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This report examines the relationship between exhaust emissions and fuel economy of automobiles. Examined are vehicle characteristics such as driveability, performance, costs, octane requirements, and production lead time. Also included is past EPA reports on fuel ecomomy and exhaust emissions, a literature search identifying other pertaint reports and finally the 1981 automobile fleet was examined and its fuel economy and exhaust emissions performance was assessed.

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Emission Control Technology Division
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SECTION I

I. Summary

This report contains analyses of the fuel economy/emissions relationships for 1981 model year and earlier vehicles. The 1981 model year Federal emission standards are the most stringent Federal standards to date. "A Study of the Relationship Between Exhaust Emissions and Fuel Economy" is the title for this report. However, this does not mean that these are the only two important variables. The relationship between the fuel economy and exhaust emissions does not exist in isolation, but rather is intertwined with many other vehicle characteristics. These associated characteristics include, but are not limited to; driveability, performance, costs, octane requirement, production lead time, and fuel economy/exhaust emissions control technology. Ideally, an examination of fuel economy/exhaust emissions relationships would include quantification of the concurrent interactions with these other vehicle characteristics. Unfortunately, neither this report nor any other reports available to EPA have identified data allowing such quantificaton.

This report is briefly summarized as follows: First, the background for the report was reviewed, including past EPA reports on fuel economy and emissions. Second, a literature search identified other reports which addressed fuel economy and emissions. Third, the 1981 car fleet was examined and its fuel economy/emissions performance assessed.

The historical fuel economy and emission standards trends show an overall trend of increasing fuel economy and decreasing emissions over time. This is not meant to imply that the reduction in emissions is necessarily a causal factor in the fuel economy rise. Many other vehicle characteristics including weight and engine displacement were also changing over this same time period.

An important observation to make and the major conclusion of this study is that the twin goals mandated by Congress for the early 1980's have essentially been met. Fuel economy has been improved substantially and emissions have been greatly reduced.

SECTION II

II. Background

This report has been prepared to examine the relationship between exhaust emissions and fuel economy of automobiles. This report treats the relationship between emissions and fuel economy in more detail than any previous EPA work. This subject is of considerable interest to EPA due to the importance of any changes in fuel economy on cost to the consumer of various emission standards. The Congress of the United States is also interested in the relationship between exhaust emissions and fuel economy. The interest of the Congress is expressed in Section 203(a) of the Provisions of Public Law 95-95 which do not amend the Clean Air Act. The Congressional interest in the subject was an important consideration in the decision to conduct this study.

"Emission control reduces fuel economy." Is it true or false? This cliche is typical of many statements which are made in reference to an interaction between vehicle emissions and fuel economy. Three very noticeable shortcomings are evident in this cliche. First, the vehicle(s) for which the emission/fuel economy relationship is being cited is not defined. Many automobile design parameters can affect a vehicle's emissions and/or fuel economy. Secondly, the implied comparison made in the example statement does not identify the basis for comparison. Gain, loss, reduction, improvement, better and worse mean nothing without a clearly stated basis of comparison. Finally, the type of emission control system is not stated. During the time period through which new vehicles have been subject to emission standards, the type of pollutants, the pollutant levels and the test procedures have all changed. In addition, the State of California has its own set of emission standards, which differ from the Federal standards.

EPA has studied and reported extensively on both vehicle fuel economy and exhaust emissions. Several of these reports have addressed the relationship between fuel economy and emission standards. Prior to a review of some conclusions from these reports, a brief discussion of fuel economy will be presented.

Fuel economy of automobiles is often expressed in terms of miles per gallon (MPG). Many methods are used to generate mpg values. EPA has developed test procedures which measure a vehicle's mileage over an "urban" driving cycle and a "non-urban" or "highway" driving cycle. Exhaust gas is monitored as a vehicle is operated over these cycles and the fuel economy is calculated using the carbon balance method discussed below.

To calculate fuel economy, in miles per gallon (MPG), from an emission test, the following equation applies:

$$\frac{\text{Miles}}{\text{Gallon}} = \frac{\text{gms carbon/gal of fuel}}{\text{gms carbon in exhaust/mile}}$$

The carbon in the fuel is:

$$\begin{aligned} \text{grams } C_{\text{fuel}} &= \frac{\text{grams fuel}}{\text{gallon}} \times \\ &\quad \frac{\text{molecular wt. C}}{\text{molecular wt. fuel}} \\ &= (2798) \times (.866) \\ &= 2423 \end{aligned}$$

where:

2798 is a density typical of test gasoline, in grams/gallon; and

.866 is typical of the weight fraction of carbon in the fuel.

The carbon in the exhaust is contained in the unburned fuel hydrocarbons (HC), carbon monoxide (CO), and carbon dioxide (CO_2), as follows:

$$\text{grams } C_{HC} = \text{gm HC} \times \frac{\text{molecular wt. C}}{\text{molecular wt. HC}}$$

$$= \text{gm HC} \times (.866)$$

$$\text{grams } C_{CO} = \text{gm CO} \times \frac{\text{molecular wt. C}}{\text{molecular wt. CO}}$$

$$= \text{gm CO} \times (.429)$$

$$\text{grams } C_{CO_2} = \text{gm } CO_2 \times \frac{\text{molecular wt. C}}{\text{molecular wt. } CO_2}$$

$$= \text{gm } CO_2 \times (.273)$$

So we have:

$$\frac{\text{Miles}}{\text{Gallon}} = \frac{2423}{(.866\text{gmHC} + .429\text{gmCO} + .273\text{gmCO}_2)/\text{miles}}$$

or

$$\text{MPG} = \frac{2423 \times \text{miles traveled}}{.866\text{gmHC} + .429\text{gmCO} + .273\text{gmCO}_2}$$

Example: In a 10-mile test, a car's exhaust emission measurements show the following amounts of carbon compounds: HC, 9 grams; CO, 124 grams; CO_2, 3641 grams.

Using the above equation, the fuel economy is:

$$\text{MPG} = \frac{2423 \times 10}{.866(9) + .429(124) + .273(3641)}$$

$$= \frac{24,230}{7.8 + 53.1 + 993.7} = \underline{\underline{23.0 \text{ MPG}}}$$

The measured fuel economies observed over these two driving cycles are the urban mileage (MPG_u) and the highway mileage (MPG_h). The MPG_u and MPG_h can be used to calculate a composite mileage (MPG_c) by means of a weighted harmonic averaging technique.

Suppose a motorist takes the following three trips:

200 miles, using 15.0 gallons;
100 miles, using 9.4 gallons;
140 miles, using 11.8 gallons.

The fuel economies of these three trips are:

$$\frac{200 \text{ miles}}{15.0 \text{ gal.}} = 13.3 \text{ MPG;}$$

$$\frac{100 \text{ miles}}{9.4 \text{ gal.}} = 10.6 \text{ MPG;}$$

$$\frac{140 \text{ miles}}{11.8 \text{ gal.}} = 11.9 \text{ MPG.}$$

If he merely averages the individual trip MPG's he gets:

$$(13.3 + 10.6 + 11.9)/3 = \underline{11.9 \text{ MPG}}$$

But this is incorrect. the motorist traveled 440 miles and used 36.2 gallons, so his overall fuel economy was:

$$440/36.2 = \underline{12.2 \text{ MPG}}$$

To get the correct fuel economy for multiple trips, the following equation must be used:

$$\frac{\text{Miles}}{\text{Gallon}} = \frac{\text{total miles traveled}}{\text{total gallons used}}$$

If the individual trip lengths and fuel economy values are known, but the gallons used are not known, the proper equation is:

$$\text{MPG} = \frac{\text{miles}_1 + \text{miles}_2 + \ldots + \text{miles}_N}{\dfrac{\text{miles}_1}{\text{MPG}_1} + \dfrac{\text{miles}_2}{\text{MPG}_2} + \ldots + \dfrac{\text{miles}_N}{\text{MPG}_N}}$$

where miles_x = length of trip "x"; MPG_x = gas mileage to trip "x"; and N = number of trips.

For a number of test trips of the same length, the above equation is equivalent to:

$$\text{MPG} = \frac{\text{miles}_t \times N}{\text{miles}_t \quad (\frac{1}{\text{MPG}_1} + \frac{1}{\text{MPG}_2} + \ldots \frac{1}{\text{MPG}_N})}$$

where miles_t = the standard test length and N = the number of tests.

The above equation simplifies to:

$$\text{MPG} = N/\text{Sum}_N \frac{1}{\text{MPG}_N}$$

which is the harmonic average of the MPGs from the tests.

To calculate the composite MPG from known city and highway MPG's, the apportionment of total mileage between city and highway driving must be used. If a motorist drives 55% of his mileage in the city and 45% on the highway, his composite fuel economy is:

$$\text{MPG} = \frac{\text{total miles}}{\dfrac{.55(\text{total miles})}{\text{City MPG}} + \dfrac{.45(\text{total miles})}{\text{Highway MPG}}}$$

$$= \frac{1}{\dfrac{.55}{\text{MPG}_C} + \dfrac{.45}{\text{MPG}_H}}$$

In addition to the carbon balance method, fuel economy can also be calculated from vehicle speed and fuel consumption rate, as follows.

$$\frac{\text{Miles}}{\text{Gallon}} = \frac{\text{Miles/Hour}}{\text{Gallons/Hour}}$$

But fuel consumption rate is related to the engine power output (not the power rating) by the expression:

$$\frac{\text{Gallons}}{\text{Hours}} = \text{HP} \times \frac{\text{lbs fuel}}{\text{HP-Hr}} \times \frac{\text{Gals}}{\text{lb}}$$

So fuel economy is:

$$\frac{\text{Miles}}{\text{Gallon}} = \frac{(\text{Mi/Hr})}{(\text{HP})} \times \frac{(\text{lbs/gal})}{(\text{lb/HP-Hr})}$$

or

$$\text{MPG} = \frac{\text{MPH} \times \text{Df}}{\text{HP} \times \text{SFC}}$$

Where Df is fuel density, pounds per gallon (approximately 6.2 for gasoline); and

SFC is specific fuel consumption, pounds per hour per horsepower output.

SFC is a commonly-used engineering term directly related to engine efficiency. The more efficient an engine is, the less fuel it needs to deliver a given power output. For a typical gasoline fuel, the relationship between SFC and engine efficiency is approximately:

$$\text{SFC} = \frac{13.5}{\text{Efficiency}}$$

(An efficiency of 13.5% corresponds to an SFC of 1.0 lb/HP-Hr)

Substituting,

$$\text{MPG} = \frac{\text{MPH} \times \text{Df}}{\text{HP} \times 13.5/\text{Eff.}} = \frac{\text{MPH} \times 6.2 \times \text{Eff.}}{\text{HP} \times 13.5}$$

So we see that fuel economy is a function of speed (MPH), engine load (HP), and engine efficiency according to:

$$\text{MPG} = .46 \ \frac{\text{MPH}}{\text{HP}} \times \text{Efficiency}$$

for a typical gasoline fuel.

Example: An intermediate size car requires an engine output of 26 HP to cruise at 50 MPH. The engine efficiency for this condition is 22.0% (SFC = 0.614). Using the above equation, the fuel economy is:

$$\text{MPG} = .46 \times 50/26 \times 22 = \underline{\underline{19.5 \text{ MPG}}}$$

To cruise at 70 MPH, the same car requires 51 HP, and the engine efficiency is 25.4% (SFC = 0.532). The fuel economy is:

$$\text{MPG} = .46 \times 70/51 \times 25.4 = \underline{\underline{16.0 \text{ MPG}}}$$

Also, note that the instantaneous fuel economy of any automobile can range from zero to infinity. Examples are a vehicle stopped with an idling engine (zero MPG) and a vehicle coasting with the engine stopped (infinite MPG).

The remainder of this section lists some conclusions which have been presented in previous EPA reports. The reader will notice that some fuel economy estimates for the same subject group of automobiles are different between reports. This is a function of the dynamic process of estimation. As time has passed, the data available to EPA have changed, and analysis technqiues have been improved.

An early EPA report* contained the following conclusions:

> Vehicle weight is the single most important parameter affecting urban fuel economy; a 5000 pound vehicle demonstrates 50% lower fuel economy than a 2500 pound vehicle.
>
> The fuel economy loss for 1973 vehicles, compared to uncontrolled (pre '68) vehicles, is less than 7%. The average fuel economy loss due to emission control for all controlled (68-73) vehicles is 7.7%.
>
> Data on 172 1970 and 1971 GM cars did not demonstrate any effect on fuel economy of reduced compression ratio.
>
> The Diesel and stratified charge engines show better fuel economy than the conventional engine with the Diesel showing a fuel economy improvement of more than 70%.

A year later, in October 1973, another EPA report** stated the following concerning emissions/fuel economy relationships:

> The sales weighted average fuel economy loss due to emission controls (including reduction in compression ratio) for 1973 vehicles, compared to uncontrolled (pre-1968) vehicles, is 10.1%. However, vehicles less than 3,500 pounds show an average 3% gain (attributable to carburetor changes made to control emissions) while vehicles heavier than 3,500 pounds show losses up to 18%. The size of these losses, however, is highly dependent on the type of control systems the manufacturer has chosen to use.
>
> The reduction in compression ratio employed by most manufacturers to enable their vehicles to operate on 91 octane gasoline has resulted in a 3.5% fuel economy loss.

---

* Fuel Economy and Emission Control, U. S. Environmental Protection Agency, Office of Air and Water Programs, Mobile Source Pollution Control Program, November 1972.

** A Report on Automobile Fuel Economy, U.S. Environmental Protection Agency, Office of Air and Water Programs, Office of Mobile Source Air Pollution Control, October 1973.

By the 1975 model year, catalytic converter equipped vehicles were being produced in sizeable numbers. In the Fall of that year, the EPA again reported on automotive fuel economy. This report* presented the following conclusions:

> There is no simple or inherent relationship between fuel economy and the emissions standards that new cars are required to meet; especially misleading is the contention that fuel economy always becomes poorer as emissions standards are made more stringent. With the use of catalyst technology, the average fuel economy of 1975 cars is nearly 24% better than the 1974 models, although their emissions are lower than the 1974's. In fact, fuel economy of the 1975's is as good as cars built before emission controls were introduced.
>
> There is no guarantee of superior fuel economy through the use of catalytic converters. 1975 cars using catalysts can give excellent or poor fuel economy, depending on the manufacturer's overall design. Cars which do not use catalysts can also give excellent or poor economy, again depending on the overall design.

At the beginning of 1975, EPA published a report which was an overview of the technical status of automobile emission control.** The chapter of this report which covered fuel economy contained the following discussion on the effects of emission standards:

> The net effect on fuel economy of a given emission standard depends on the combination of control techniques used to achieve compliance. Analysis of EPA certification data has clearly shown that the fuel economy performance of nominally identical cars (e.g. same weight, engine size, axle ratio, etc.) can be significantly different while the emissions are nearly the same.

---

* Factors Affecting Automotive Fuel Economy, U.S. Environmental Protection Agency, Office of Air and Waste Management, Mobile Source Air Pollution Control, Emission Control Technology Division, September 1975.

** Automobile Emission Control - The Technical Status and Outlook as of December 1974, A Report to the Administrator, U.S. Environmental Protection Agency, Mobile Source Pollution Control Program, Emission Control Technology Division, January 1975.

> The difference in fuel economy is the result of the difference in the usage of fuel efficient control technology. At a fixed emission level fuel economy is a function of the usage of fuel efficient control technology.
>
> Erroneous conclusions about emission control and fuel economy can result from ignoring differences in the control technology available and looking at the effect of different levels of emission control using a particular control system. With a fixed emission control system fuel economy is a function of the degree of emission control required. When alternative control approaches are not considered, changes in emission level can only be achieved by altering basic engine calibrations such as spark timing. Since minimum emissions and maximum fuel economy are usually not simultaneously achieved, lower emission levels with a given system result in degraded fuel economy.
>
> Besides looking at emission control system/emission level/fuel economy relationships with the control system held constant or the emission levels held constant, it is also possible to consider the fuel economy level held constant. With a fixed level of fuel economy the degree of emission control achievable depends on the type of control technology used. For example, the change in emission level from uncontrolled to the 1975 Federal Interim levels (1.5, 15, 3.1) has been accomplished at a fixed fuel economy level by selection of lean engine calibrations and catalytic exhaust treatment systems.
>
> The three underlined statements above are three different ways of looking at control system/emission level/fuel economy relationships. Each statement is a two-dimensional analysis of a three dimensional problem, however. Unless one fully understands the three dimensional aspects of the tradeoffs involved, it is possible to be misled about the expected impact of a particular emission standard. Since there is no fixed relationship between fuel economy and emission standards, it is impossible to guarantee a change in fuel economy by a change in emission standards.

Every year since 1975 EPA authors have written Society of Automotive Engineers (SAE) papers that discuss the current status and trends in fuel economy and, more importantly for this report, discuss estimates of the various reasons why the fuel economy of one group of vehicles might be different from the fuel economy of another group. Some of the differences have been attributed to emissions or to emission standards in the past.

A summary of these reports is shown below.

Previous Reports That Contain Fuel Economy and Emissions Discussions

Year	SAE Paper	Title
1978	780036	Light Duty Automotive Fuel Economy... Trends Through 1978
1979	790225	Light Duty Automotive Fuel Economy... Trends Through 1979
1980	800853	Passenger Car and Light Truck Fuel Economy Trends through 1980
1981	810386	Light Duty Automotive Fuel Economy... Trends through 1981
1982	820300	Light Duty Automotive Fuel Economy... Trends through 1982
1983	830544	Light Duty Automotive Fuel Economy... Trends thru 1983

This section has only touched upon some highlights from previous EPA technical reports which addressed the emissions versus fuel economy issue. The following bibliography is provided to assist those readers who wish to obtain the reports which were reviewed in preparation of this section.

Bibliography

1. Automobile Emission Control - A Technology Assessment As Of December, 1971, U.S. Environmental Protection Agency, Mobile Source Pollution Control Program, Office of Air Programs, January 1, 1972.
2. Fuel Economy and Emission Control, U.S. Environmental Protection Agency, Office of Air and Water Programs, Mobile Source Pollution Control Program, November, 1972.
3. A Report on Automobile Fuel Economy, U.S. Environmental Protection Agency, Office of Air and Water Programs, Office of Mobile Source Air Pollution Control, October, 1973.
4. Automobile Emission Control - The Development Status As of April 1974, A Report to the Administrator, U.S. Environmental Protection Agency, Mobile Source Pollution Control Program, Emission Control Technology Division, April, 1974.
5. Automobile Emission Control - The Technical Status and Outlook as of December 1974, A Report to the Administrator, U.S. Environmental Protection Agency, Mobile Source Pollution Control Program, Emission Control Technology Division, January, 1975.
6. Tradeoffs Associated With Possible Auto Emission Standards, A Report to the Administrator, U.S. Environmental Protection Agency, Mobile Source Pollution Control Program, Emission Control Technology Division, February, 1975.
7. Factors Affecting Automobile Fuel Economy, U.S. Environmental Protection Agency, Office of Air and Waste Management, Mobile Source Air Pollution Control, Emission Control Technology Division, September, 1975.

8. Automobile Emission Control - The Current Status and Development Trends as of March 1976, A Report to the Administrator, U.S. Environmental Protection Agency, Office of Mobile Source Air Pollution Control, Technology Assessment and Evaluation Branch, Emission Control Technology Division, April, 1976.

9. Automobile Emission Control - The Development Status, Trends, and Outlook as of December 1976, A Report to the Administrator, U.S. Environmental Protection Agency, Office of Air and Waste Management, Mobile Source Air Pollution Control, Emission Control Technology Division, April, 1977.

SECTION III

III. Fleet Level Effects

III A. Fuel Economy of 1974 and Newer Vehicles Compared to Uncontrolled Vehicles

The summary of most fuel economy/emission relationships studies is represented in a figure like that shown in figure III.A-1. In general, those that claim fuel economy penalties for controlling emissions have estimates in the region labeled A. In region A, for each and every percentage reduction there is a penalty and the percentage value of the penalty increases as the stringency increases. EPA can fairly be said to have made estimates like those shown in B in the past - a small effect - it could go either way. Almost nobody can be found that espouses the relationship labeled as C in the figure.

In order to investigate this issue with some data, SAE paper 810386* was studied. The nominal emission standards in figure 4 of that reference were transformed to percent reductions from an uncontrolled base of 8.7 HC, 87.0 CO, 3.5 NOx. The base, nominal emissions standards and percent reductions are shown in table III.A-1, along with the constant-weight-mix fuel economy ratio. The term "nominal emission standard" is used to denote the most typical emission requirement, and is used to account for those cases where waivers (1981 Federal) or optional standards (California) make a single triplet of values not precisely correct.

The analysis is based on each model year's total fuel economy change from the pre-emission control level and total emission standards change, also from the pre-control level. The data in table III.A-1 are presented graphically in figure III.A-2 through figure III.A-4. It should be pointed out that these figures are at a constant weight mix, so that the improvement in fuel economy due to reduced weight cars taking a larger

---

* J.A. Foster, J.D. Murrell, and S.L. Loos, SAE Paper 810386, "Light Duty Automotive Fuel Economy....Trends through 1981", U.S. EPA.

Figure III. A-1

Concepts of Changes in Fuel Economy with Changes in Stringency of Emission Standards

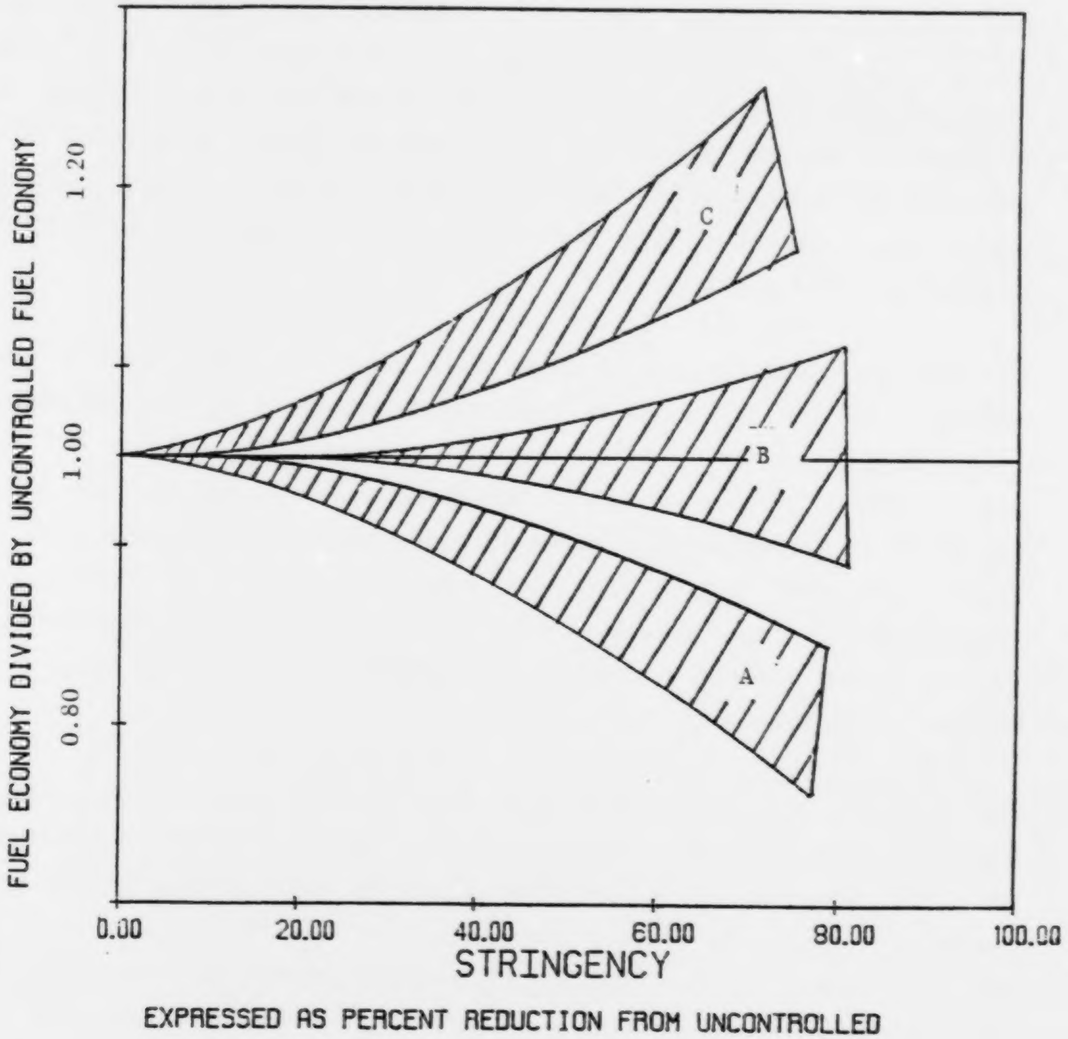


Table III. A-1

Percent Emission Reductions and Fuel Economy Ratios Compared to Uncontrolled Emissions and Fuel Economy (Nominal Emissions Standards)

Year	Fed or Cal	HC Standard (% Red)	CO Standard (% Red)	NOx Standard (% Red)	MPG Ratio**
pre - control		8.7 (0%)	87 (0%)	3.5 (0%)	1.00
1974	Fed***	3.0 (66%)	28. (68%)	3.1 (11%)	1.00
1974	Cal***	2.9 (67%)	28 (68%)	2.1 (40%)	0.94
1975	Fed	1.5 (83%)	15 (83%)	3.1 (11%)	1.14
1975	Cal	0.9 (90%)	9.0 (90%)	2.0 (43%)	1.07
1976	Fed	1.5 (83%)	15 (83%)	3.1 (11%)	1.26
1976	Cal	0.9 (90%)	9.0 (90%)	2.0 (43%)	1.12
1977	Fed	1.5 (83%)	15 (83%)	2.0 (43%)	1.30
1977	Cal	0.41 (95%)	9.0 (90%)	1.5 (57%)	1.14
1978	Fed	1.5 (83%)	15 (83%)	2.0 (43%)	1.30
1978	Cal	0.41 (95%)	9.0 (90%)	1.5 (57%)	1.14
1979	Fed	1.5 (83%)	15 (83%)	2.0 (43%)	1.28
1979	Cal	0.41 (95%)	9.0 (90%)	1.5 (57%)	1.17
1980	Fed	0.41 (95%)	7.0 (92%)	2.0 (43%)	1.32
1980	Cal	0.41 (95%)	9.0 (90%)	1.0 (71%)	1.26
1981	Fed	0.41 (95%)	3.4 (96%)	1.0 (71%)	1.43
1981	Cal	0.39* (95%)	7.0 (92%)	0.7 (80%)	1.39

---

* 0.39 NMHC treated equal to 0.41 THC for this study

** From SAE paper 810386, page 13, figure 4

*** Approximate 1975 FTP equivalent

Figure III. A-2

Fuel Economy of the Federal and California Fleets Divided by the Fuel Economy of Uncontrolled Vehicles Versus Stringency of the HC Standard

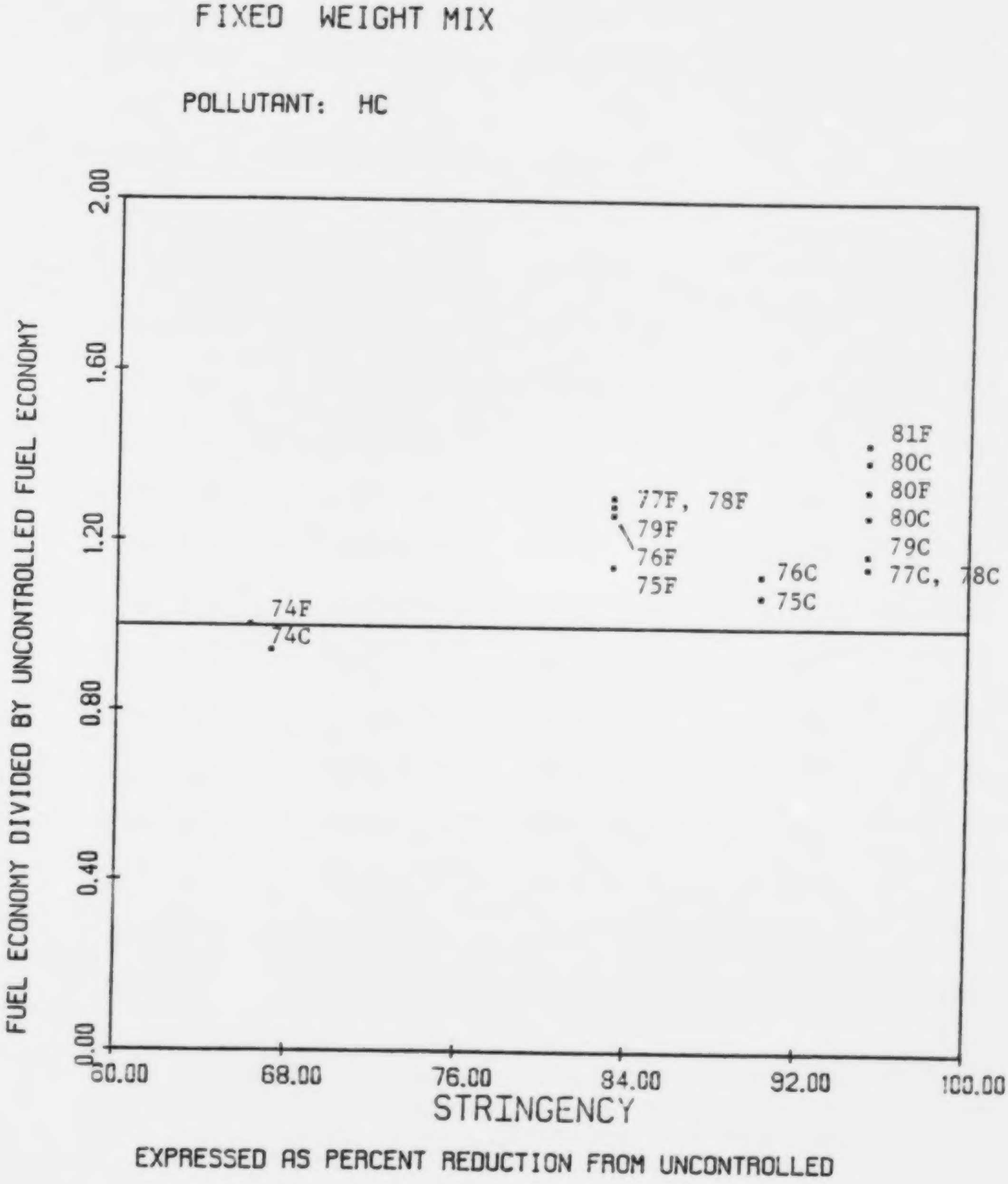


Figure III. A-3

Fuel Economy of the Federal and California Fleets Divided by the Fuel Economy of Uncontrolled Vehicles Versus Stringency of the CO Standard

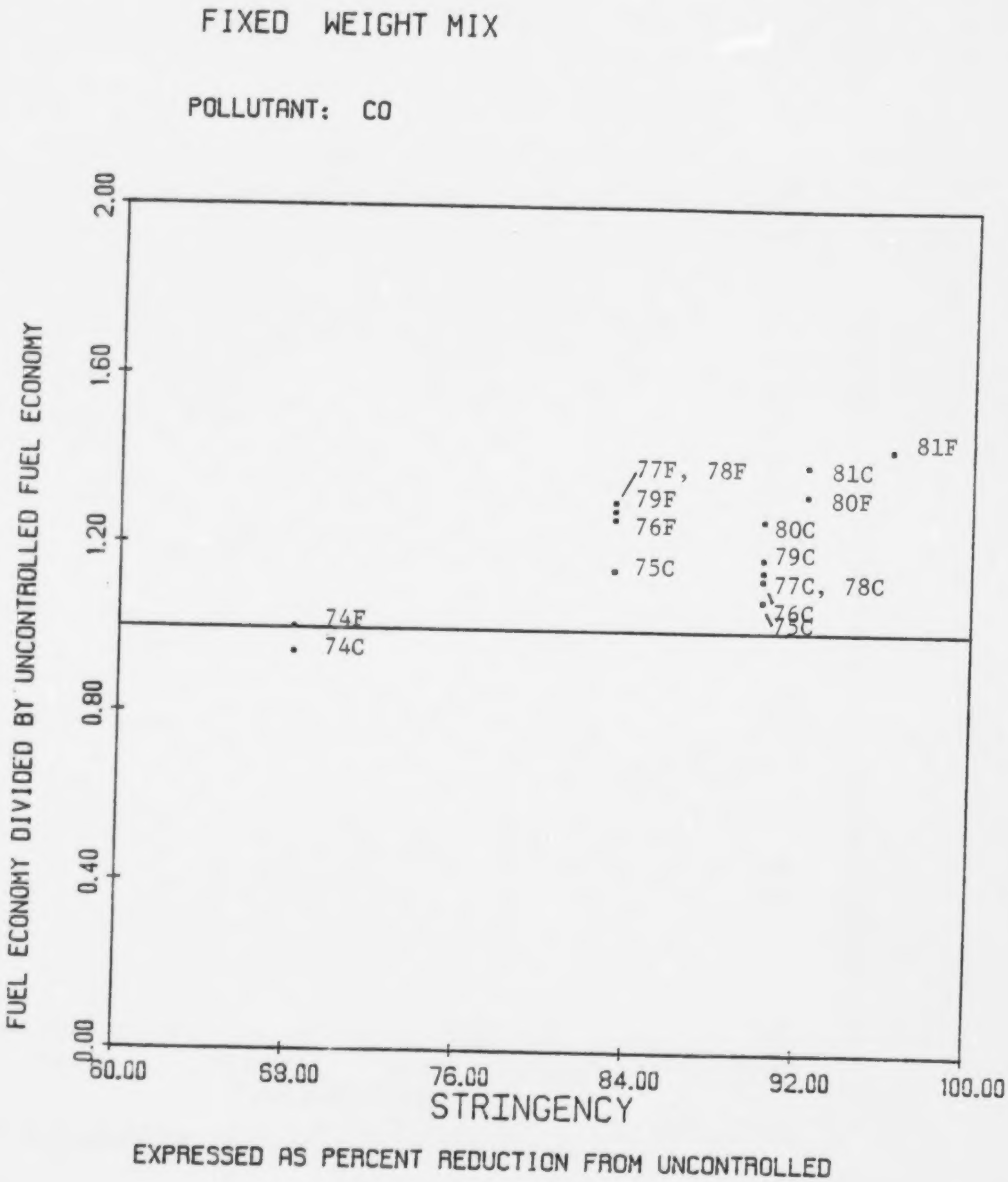
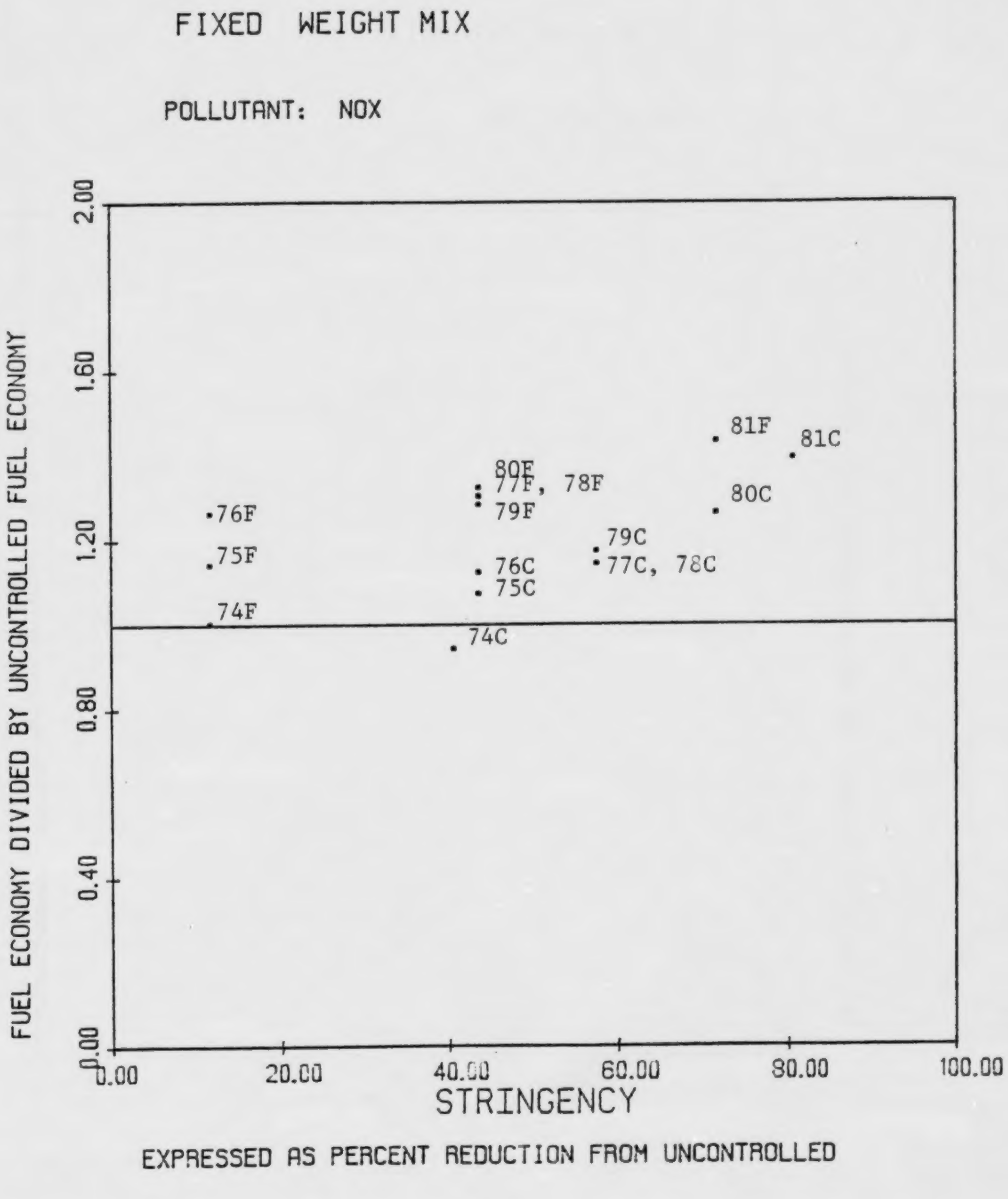


Figure III. A-4
Fuel Economy of the Federal and California Fleets
Divided by the Fuel Economy of Uncontrolled Vehicles
Versus Stringency of the NOx Standard



fraction of the fleet is not shown. Something else other than weight is responsible for the trends. The figures show that since 1975 there have been no combinations of emissions standards that have caused fuel economy to fall below the line. There is not much of a trend for HC and CO, but that could be because they both fall between about 66% and 95% in percent reduction space. For NOx there is a wider spread, from 11% reduction to 80% reduction, but there does not seem to be a consistant trend here either. One thing is clear, however, if there is a trend such as A (figure III A-1) in the data it is not showing up at the constant weight level of aggregation. If anything, the data seem to reflect a trend more like the "C" example.

III. B. Fuel Economy of 1975 and Newer Vehicles Compared to Previous Year Vehicles

Another way of associating fuel economy changes with emission standards is to compare each model year's fuel economy and emission standards with those of the preceding year. This has been done using two methods.

The first method considers the Federal and California vehicle fleets separately and considers fuel economy of these fleets on a constant weight basis. The constant weight basis is the 1978 model year weight mix of the Federal fleet. Referring to the emission standards given earlier in table III.A-1 for the various model years, this approach assigns (for example) a 35% reduction in the 49-States NOx standard for 1977 (2.0 grams/mile) compared to 1976 (3.1 grams/mile), and a 50% reduction in the 49-States NOx standard for 1981 (1.0 grams/mile) compared to 1980 (2.0 grams/mile). The weight-normalized fuel economy changes for the 49-States and California fleets can then be linked to the emission standards changes of the same two subfleets.

The second method treats year-to-year changes in emission standards as a value equal to the 49-States change weighted 90% and the California change weighted 10%. This yields an emission change representing a pooled 50-States value. The corresponding 50-States year-to-year changes in fuel economy are determined using a different analytical technique than the weight-normalization used above. This technique isolates the fuel economy change due to factors other than changes in weight mix, changes in engine mix within the weight classes, and changes in transmission mix shifts within discrete weight/engine combinations. The method is described more fully in appendix 2 of this report. Suffice it to say here that the resulting fuel economy change, dubbed "system optimization", provides a better estimate (than weight-normalized) of the fuel economy change due only to emission standards and the emission control technology employed to meet those standards.

Table III.B-1 gives the results of these two methods of year-to-year analysis. Using either method, this table shows that along with year-to-year changes in emission standards which have always been downward, fuel economy changes have always been upward (with the single exception of 1979, when fuel economy dropped in response to factors other than emissions standards, which were unchanged from 1978). Figures III.B-1, III.B-2, and III.B-3 illustrate the data from table III.B-1.

In general it should be noted that the fuel economy went up in some years when the year-to-year change in a given emissions standard was zero. These are plotted on the figures as zero percent reductions. Figure III.B-1 shows that fuel economy tended to go up when no change was made in the HC emission requirements. As in the case where the comparison was made to uncontrolled vehicles as a base, figures III.B-1, III.B-2, and III.B-3 indicate no penalty for changes made from one year to the next even when these changes are substantial reductions in emissions. In fact the resulting fuel economy effects are shown to be positive, not negative.

III. C. Fuel Economy of Federal versus California Vehicles

There is yet another method of analysis that can be applied to the certification data. Within a given model year, the system optimization fuel economy difference between the 49-States and California fleets can be compared, along with the differences in 49-States and California emission standards. This would indicate, at a fixed point in time, the fuel economy effects of two levels of emission standards. If one assumes that at a given

Table III. B-1

Changes in Emission Standards and Fleet Fuel Economy Compared to the Previous Year Values

	-----Method 1------ (Federal and California Fleets Separately)		------Method 2------ (Federal and California Fleets Combined)	
Year	Change in Emission Std.	Weight-Normal FE Change**	Change in 50-State Emission Std.	50-States System Optim. FE Change***
74-75	Fed HC, -50% CO, -46% Cal HC, -69% CO, -68% NOx, -5%	Fed, +14% (1.14) Cal, +14% (1.14)	HC, -52% CO, -48% NOx, -0.5%	+11.5% (1.12)
75-76	No Change	Fed, +11% (1.11) Cal, +5% (1.05)	No Change	+ 8.8% (1.09)
76-77	Fed NOx, -35% Cal HC, -54% NOx, -25%	Fed, +3% (1.03) Cal, +2% (1.02)	HC, -5.4% NOx, -34%	+ 2.8% (1.03)
77-78	No Change	No Change	No Change	+ 0.5% (1.01)
78-79	No Change	Fed, -2% (0.98) Cal, +3% (1.03)	No Change	- 2.3%* (0.98)
79-80	Fed HC, -73% CO, -53% Cal NOx, -33%	Fed, +3% (1.03) Cal, +8% (1.08)	HC, -66% CO, -48% NOx, -3.3%	+ 2.6% (1.03)
80-81	Fed CO, -51% NOx, -50% Cal CO, -22% NOx, -30%	Fed, +8% (1.08) Cal, +10% (1.10)	CO, -48% NOx, -48%	+ 2.7% (1.03)

---

* More than half of this change in FE was due to test procedure changes (dynamometer loading) made to restore the rigor of the 1975 procedure - See SAE 790225, Appendix C. The net system optimization change independent of this test procedure effect is estimated at -1.0%.

** Calculated values from figure 4 of SAE Paper 810386, page 13.

*** From SAE Paper 800853, page 36.

Figure III. B-1

% Change in Fuel Economy Versus
% Change in HC Standard
from Previous Year

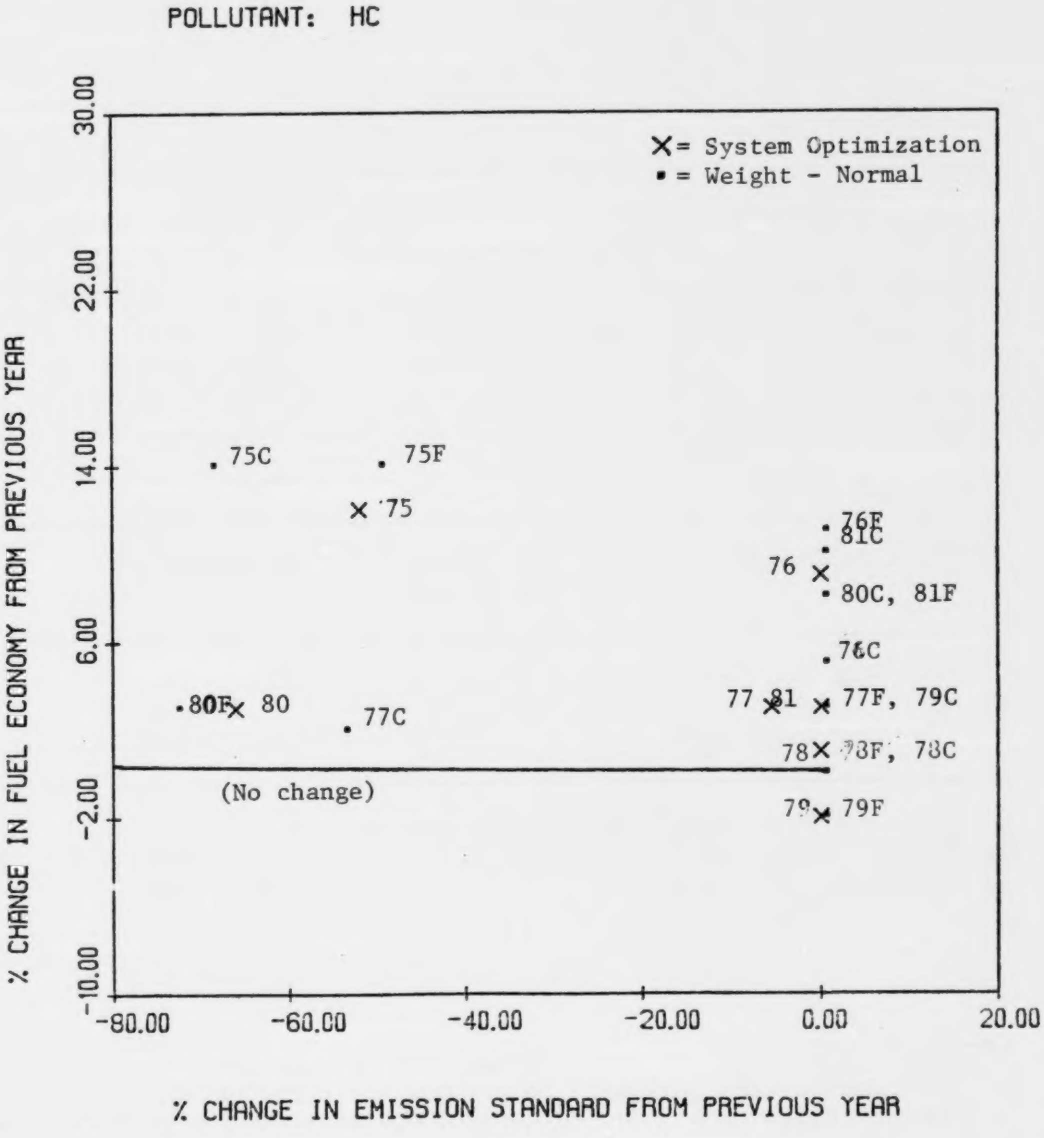


Figure III. B-2

% Change in Fuel Economy Versus
% Change in CO Standard
from Previous Year

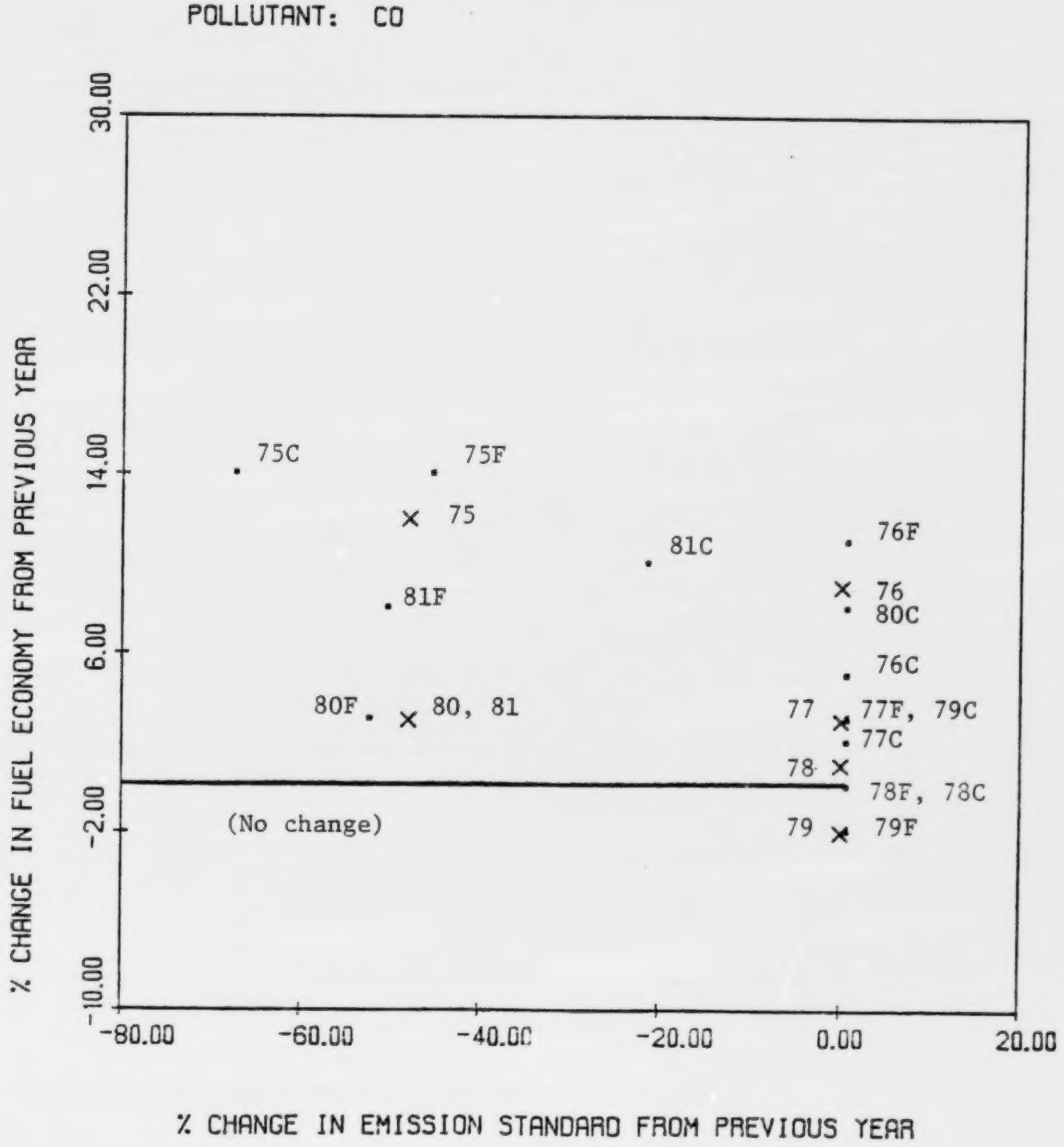
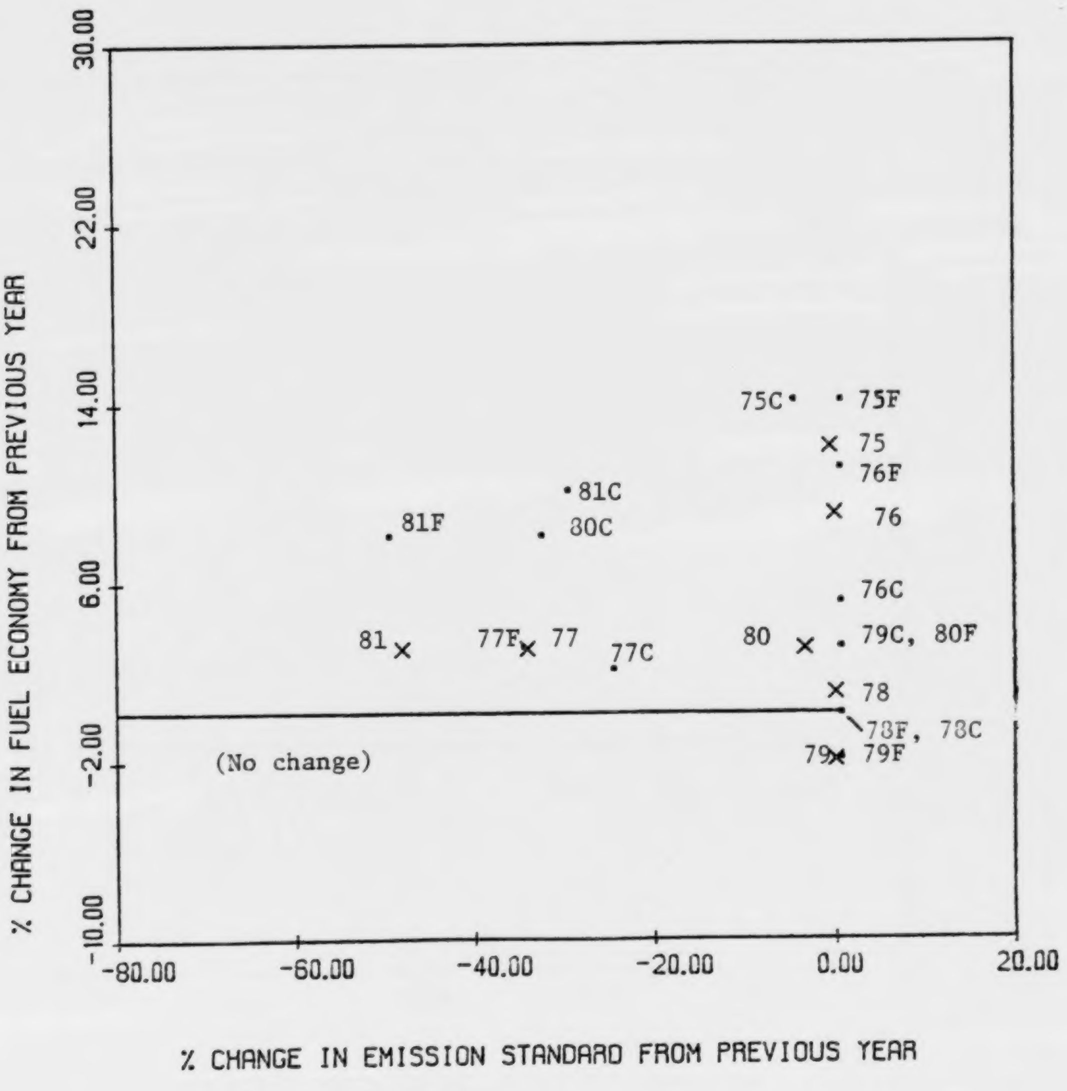


Figure III B-3

% Change in Fuel Economy Versus % Change in NOx Standard From Previous Year

POLLUTANT: NOX



point in time, roughly the same emission control and fuel economy technology is available to the Federal (49-States) and California fleets, then the technological capability could be said to be the same. This is probably roughly the case, but it must be pointed out that the emission control technology used in California in a given year in some cases is more sophisticated, due to the use of California as a proving ground for the newer technology. The results of using this method are given in table III.C-1. Figures III.C-1, III.C-2 and III.C-3 illustrate the data of table III.C-1.

Looking at table III.C-1 and figures III.C-1 through III.C-3 it can be seen that the nature of the relationship has changed. Comparing 49-States to California for the same year generally shows California to be more stringent in emissions and lower in fuel economy.

From table III. C-1 the Federal vs. California data appear at first to be five equations in four unknowns:

$$-73h - 40c - 25n + k = -11.8f$$

$$-73h - 40c - 25n + k = -11.1f$$

$$-73h - 40c - 25n + k = -10.1f$$

$$-0h + 29c - 50n + k = -4.6f$$

and

$$-0h + 106c - 30n + k = -1.7f$$

where: h, c, and n = % change in HC, CO, and NOx coefficients respectively f= % change fuel economy and k = constant.

At second glance, however, the first three equations have no possible unique solutions for h, c, and n, since the right sides of the three equations are unequal. Also, the constant terms (k) have no basis in reality, since the FE change due to no emissions changes must be zero (treating emission differences as the sole source of FE change). Interpreting the -11.8, -11.1, and -10.1 figures as random variances around the true Δ FE that comes from a combined -73% Δ HC, -40% Δ CO, and -25% Δ NOx, we can average them and construct 3 equations. Setting k = 0, there are now 3 equations in 3 unknowns.

Table III. C-1

Federal vs. California Emissions and Fuel Economy (System Optimization Method)

Year	Difference in Emission Standard	System Optimization FE Difference*
1977	HC, -73% CO, -40% NOx, -25%	-11.8% (0.88)
1978	HC, -73% CO, -40% NOx, -25%	-11.1% (0.89)
1979	HC, -73% CO, -40% NOx, -25%	-10.1% (0.90)
1980	HC, "same" CO, +29% NOx, -50%	-4.6% (0.95)
1981	HC, "same" CO, +106% NOx, -30%	-1.7% (0.98)

---

*From SAE paper 800853, page 50, and SAE paper 810386, page 12

Figure III. C-1

% Difference in Fuel Economy Versus % Difference in HC Standard for the California Fleet Compared to the Federal Fleet in the Same Model Year

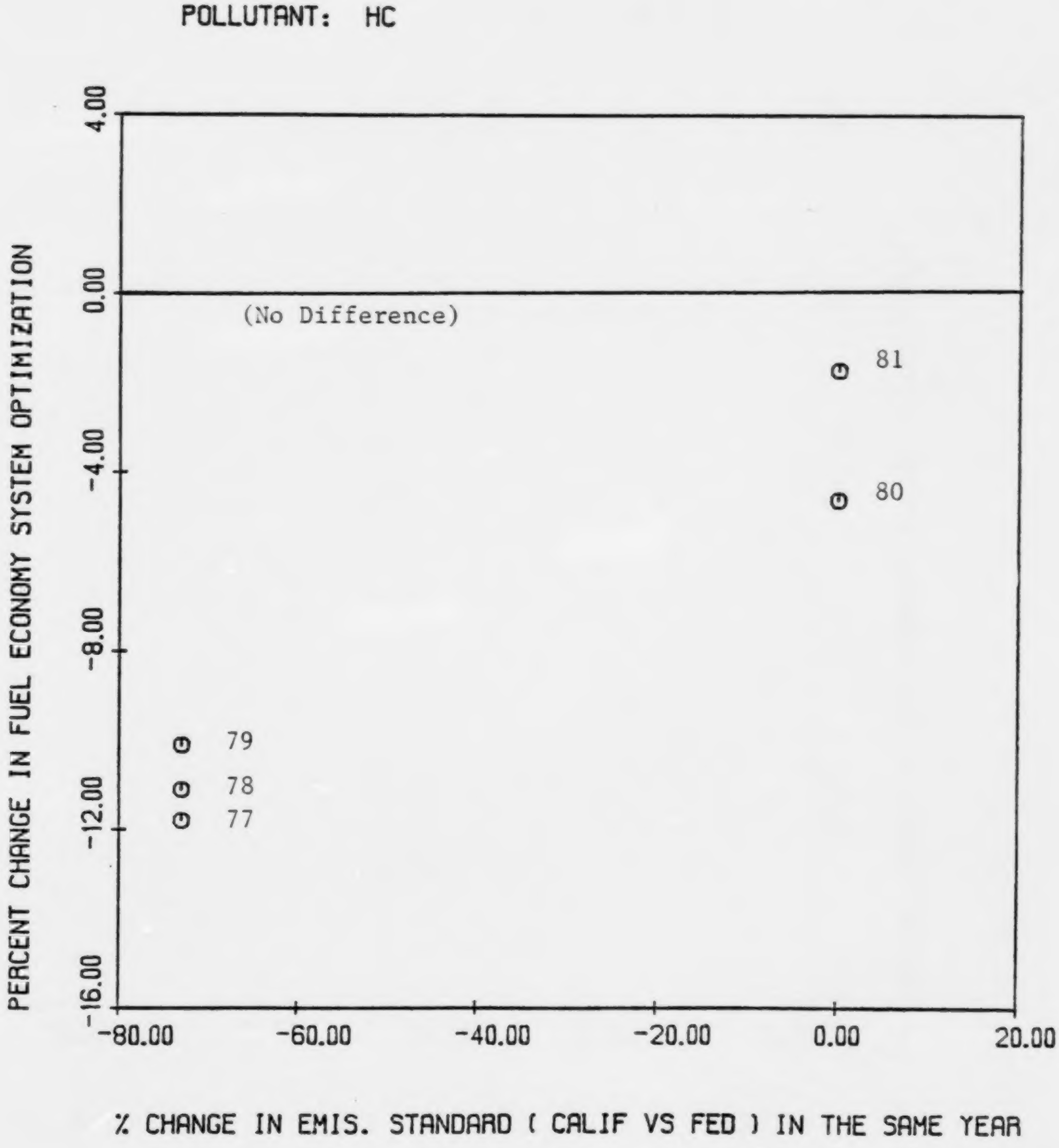


Figure III. C-2

% Difference in Fuel Economy Versus % Difference in CO Standard for the California Fleet Compared to the Federal Fleet in the Same Model Year

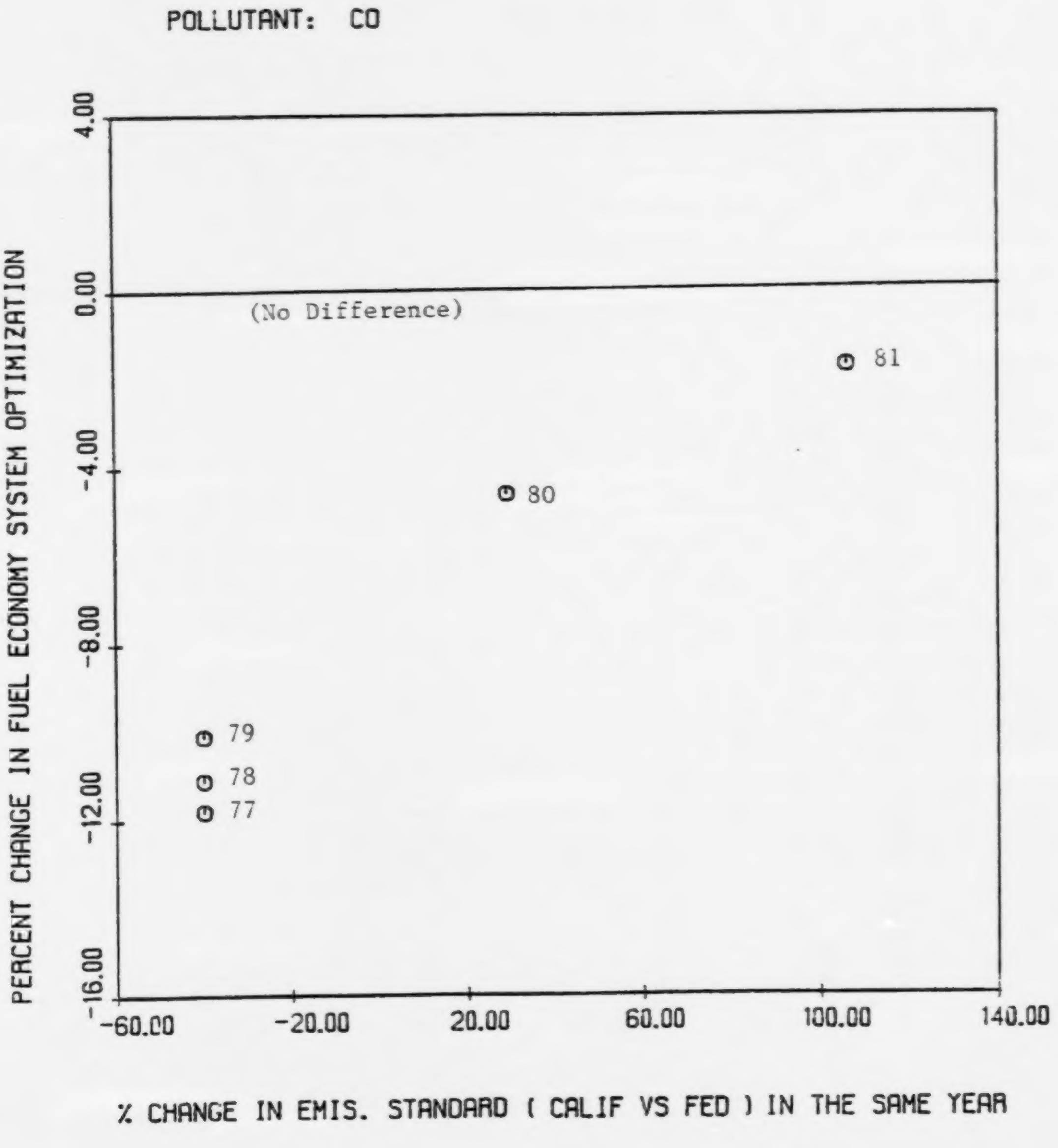
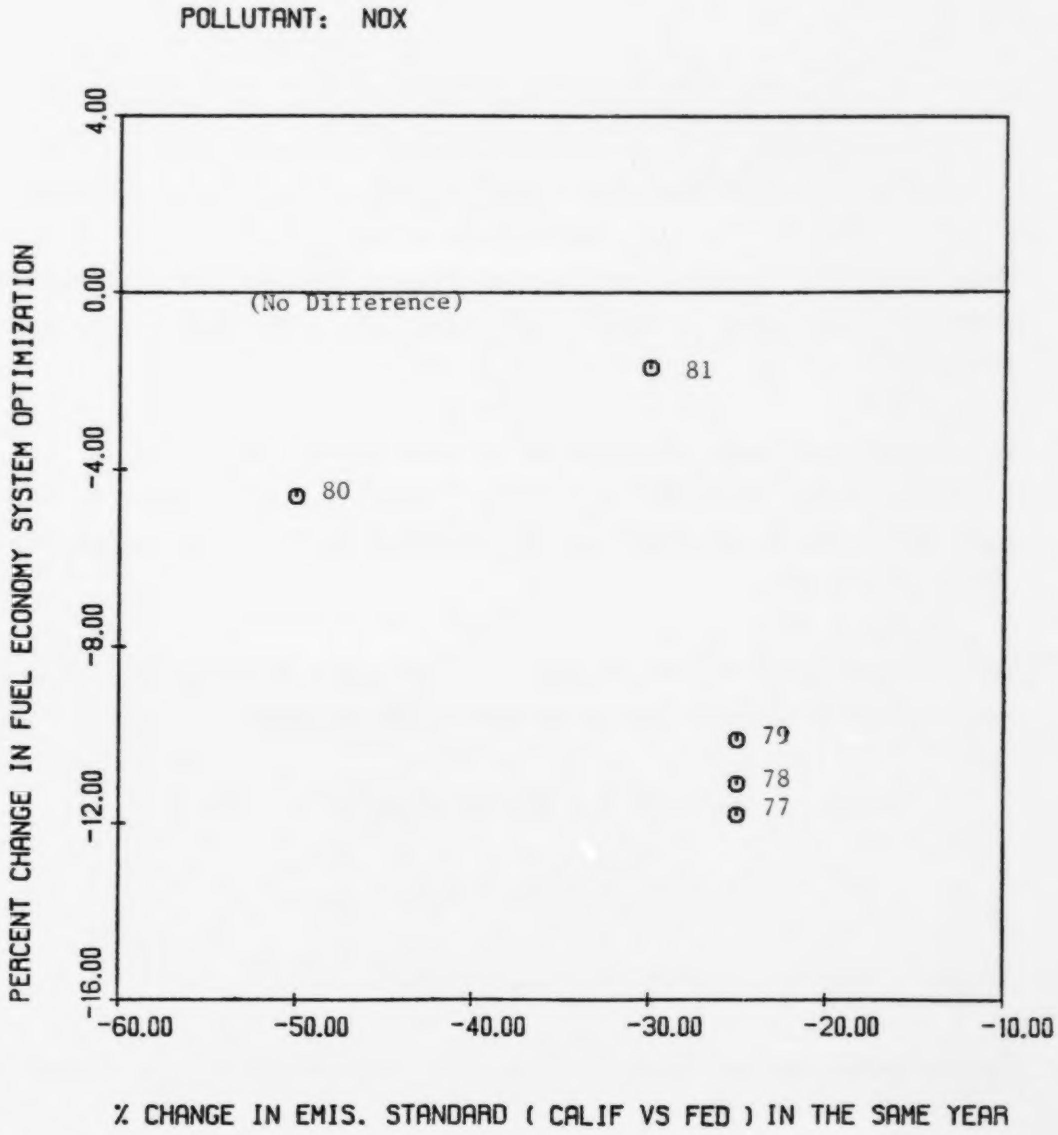


Figure III. C-3

% Difference in Fuel Economy Versus % Difference in NOx Standard for the California Fleet Compared to the Federal Fleet in the Same Model Year



$$-73h \quad -40c \; -25n = -11.0f \qquad\qquad 11.0 = \frac{11.8 + 11.1 + 10.1}{3}$$

$$+29c \; -50n = \; -4.6f$$

$$+106c \; -30n = \; -1.7f$$

The solution to this system is:

$h = 0.110246$, $c = 0.011964$, $n = 0.098939$

(all decimals are necessary)

So the dependence of $\% \Delta$ FE on $\% \Delta$ X, where X = HC, CO, NOx is:

$$\% \Delta \text{ FE} = .110246 \; (\% \Delta \text{ HC}) + .011964 \; (\% \Delta \text{ CO}) + .098939 \; (\% \Delta \text{ NOx})$$

Note that all coefficients are positive, meaning that if any emission standard goes down (tighter control), FE also goes down (suffers a penalty).

In the ballpark sense, FE responds at 1/10 sensitivity to HC and NOx changes (lowering either standard by 50% would penalize fuel economy by 5%), but is less sensitive to CO (lowering the CO standard by 50% would penalize FE by .012 x 50 = 0.6%).

The previous equation can be used to calculate a fuel economy difference for sets of standards which may be of particular interest:

1. Base 0.41 HC, 3.4 CO, 1.0 NOx

2. "80" 0.41 HC, 7.0 CO, 2.0 NOx

3. "Hybrid" 0.41 HC, 7.0 CO, 1.5 NOx

The HC change for all cases is zero. For Base versus "80" or Hybrid the CO change is (7.0 - 3.4)/3.4 = 1.058824 (105.8824%). The NOx changes are 1.0000(100%) and 0.5(50%).

"80" vs. Base = 0.110246(0) + 0.011964(105.8824) + 0.098939(100)

"80" vs. Base = 0 + 1.266770 + 9.8939 = +11.2%

Hybrid vs. Base = 0 + 0.922320 + 4.946950 = +6.2%

Note that this is the only fuel economy relationship quantified. The other positive trends could also have been quantified.

As a check on the accuracy of the equation relating Federal and California fuel economy in the same model year for more general application, the change in fuel economy from the 1980 to the 1981 Federal standards was compared. In the previous calculations, this would be the negative of "80" vs. Base or a predicted loss of 11.2% fuel economy for this change in emission standards. This compares poorly with the 2.7% increase in fuel economy from 1980 to 1981 due to system optimization (from table III.B-1), both in sign and in magnitude, and leads to the conclusion that while the California/Federal relationship for prior years may be quantifiable, that relationship has little utility when one attempts to predict changes due to differences in Federal or 49-State emission standards.

In summary, California vehicles have achieved less fuel economy than their Federal counterparts in recent years. The difference has been declining and is now 1.7% less.

III. D. The Relationship Between Emission Standards or Levels and In-use Fuel Economy

III. D.1 Background

For the past four years EPA and DOE have analyzed differences between EPA test fuel economy and "on-road" fuel economy of in-use cars. The purpose of that work was to measure fuel economy shortfall, that is, the offset between "on-road" fuel economy and fuel economy as measured on EPA tests. The fleet shortfalls reported in the 404 Report* are typical of the results of these early analyses;

Model Year	Road Shortfall (vs. EPA Composite MPG)
1974	- 6.9%
1975	-12.4%
1976	-19.2%
1977	-19.6%
1978	-19.2%
1979	-16.1%

Note that the shortfall increases with time (model year) through 1977, after which it decreases. Before attempting to relate this trend to possible emissions influences, however, we must consider the matter of vehicle technology.

Since model year 1978, manufacturers have introduced changes both in engine technologies and in drivetrains that result in a much less homogeneous mix of technologies in the U.S. fleet. Recent analysis disaggregates the large sample of in-use vehicles in the current data base (model years 1978 to 1980) into technology-specific subgroups to consider the shortfall for each technology subgroup.

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* EPA, "Passenger Car Fuel Economy: EPA and Road", Report EPA-460/3-80-010, September, 1980.

For the purposes of this discussion, the following technologies are defined as "conventional" technologies.

- Front engine, rear wheel drive vehicles
- Spark ignition (S.I.) gasoline engines
- Carburetor for fuel metering
- Automatic transmissions

The 1974-78 vehicles studied in early analyses employed predominantly conventional technologies. "Alternative" technologies are defined as follows:

- Gasoline fuel-injection for fuel metering
- Front engine, front-wheel drive vehicles
- Diesel engines
- Manual transmissions

A contractor working for both EPA and DOE has recently performed a statistical analysis of the current in-use data base to study shortfall for technology-specific subgroups of vehicles. The results of this analysis suggest that vehicles utilizing some of these alternative technologies had lower shortfall than conventional technology vehicles.

The objective of this discussion is to examine the engineering principles that govern the MPG performance of alternative technologies on the EPA test procedure and under in-use conditions. The results can be used to interpret the observed shortfalls of alternative technologies. The discussion examines each of the four technologies in comparison to their conventional technology counterpart. Thus, manual transmissions are compared to automatics, fuel injected S.I. engines to carburetted S.I. engines, front-wheel drive vehicles to rear-wheel drive vehicles and Diesel engines to carburetted S.I. engines. The synergy between multiple alternative technologies is not examined in this analysis, although it may be that vehicles with combinations of these technologies will exhibit greater reductions in shortfall than will any single application of technology.

Differences in shortfall of the four technologies in comparison to conventional technologies are associated with responses to the following performance factors:

- The response of the technology to the EPA test procedure (FTP and HFET). The EPA fuel economy is measured over fixed driving cycles on a dynamometer and the technology's response to the EPA procedure will affect the shortfall.
- The in-use maintenance characteristics of the technology. The state of tune of the vehicle is an important contributor to shortfall.
- The response of the technology to non-FTP driving conditions. The effects of cold ambient temperatures, extended idling and different driving cycles are also important contributors to shortfall.

Manual Transmissions

Earlier studies on shortfall showed that between model years 1974 and 1977, shortfall for manuals started at a level on par with automatic transmissions in 1974 and increased to approximately 10 percent above the shortfall for automatics by 1977. EPA* explained that manual transmission shift points were variable in the hands of the user, whereas the automatic was calibrated to shift at preprogrammed points. It was also suggested that vehicle owners drove, on the average, more aggressively than on the EPA cycle, i.e., the shifts are generally at higher engine speed/load points thus leading to higher shortfall for manual transmission equipped vehicles in comparison to those equipped with automatic transmissions.

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* Ibid.

New analyses by Ford, GM, and DOE contractors, with much larger and more recent data bases show the reverse to be true, i.e., manuals have less shortfall than automatic transmissions. The data bases included vehicles from model years 1978 through 1980. While the earlier results may be suspect because of the small sample of vehicles with manual transmissions in the data base, there may be two technological reasons behind this change: (i) EPA changed the manual transmission shift points during the FTP for model year 1979 and succeeding years. In previous years, manufacturers were allowed to specify shift points and patterns which were often unrealistic, but which tended to maximize fuel economy on the FTP. EPA changed the test requirements to restore the rigor of the 1975 procedure, and appears to have succeeded in reducing shortfall for vehicles equipped with manual transmissions. However, automatic transmissions were unaffected by this ruling, leading to one explanation for the observed change in relative shortfall. (ii) As fuel economy became more important, manufacturers optimized shift points for automatic transmissions so that upshifts occured as early as possible and downshifts were delayed during the FTP cycle. Torque convertor lock-up was also calibrated for maximum effectiveness on the FTP, i.e., the lock-up is engaged more frequently on the test than in "real-world" driving. This may have led to an increase in shortfall for newer automatics in comparison to automatic transmission equipped vehicles of earlier years. This, in turn, provides a second explanation for the observed changes in relative shortfall between manual and automatic transmissions.

Fuel Injection

EPA's Emission Factors program annually tests a large sample of vehicles on the FTP and checks these vehicles for maladjustments and mistuning. EPA has noted that carburetor idle mixture and choke maladjustments are the most common malperformances in these vehicles and that the adjustments were predominantly richer than the manufacturers' recommendations, leading to fuel economy reductions as large as 10 percent depending upon the degree of maladjustment.

Fuel injection systems could be expected to have lower shortfall than carburetted vehicles primarily because most users are less likely to tamper with fuel injection systems than carburetted vehicles, for two reasons. One reason for tampering and maladjustment is customer dissatisfaction with driveability, and it is generally conceded that fuel injection vehicles offer superior driveability in comparison to carburetted vehicles. The second reason for a possible relatively low level of maladjustments in fuel injected vehicles is user unfamiliarity with the system, leading to reduced tampering. However, these differences could diminish for MY 1981, because the choke and idle mixture will be much less easy to adjust in use.

Fuel injected vehicles also should have lower shortfall than carburetted vehicles because, at low ambient temperatures and during transients, fuel injected vehicles need less enrichment than carburetted vehicles. A Canadian study* found that fuel injected vehicles showed smaller decreases in fuel economy at cold ambients in comparison to carburetted vehicles. This is the result of fuel being delivered to the intake ports, rather than to the intake manifold as in carburetted vehicles where excess fuel is required to ensure adequate evaporation and transport of fuel to the cylinders. The precise delivery of fuel possible in fuel injected vehicles also reduces the need for enrichment during transient operation. Operation at ambient temperatures below those encoutered on the FTP, and rapid accelerations and decelerations not encountered on the FTP, are important causes of shortfall.

Front-Wheel Drive

On the chassis dynamometer, FWD vehicles are penalized relative to rear wheel drive (RWD) vehicles, regardless of whether the power absorption unit (PAU) setting on the dyamometer is determined by coastdown techniques or by EPA's "cookbook" method. To a large extent it is believed that this is because the FWD vehicle places a greater load on the driven wheels than a RWD vehicle. For example, a FWD vehicle with a 60/40 weight distribution will have 33 percent more load on the driving wheels than a RWD vehicle with a 55/45 weight distribution. These distributions are nominal values for each type. The additional load on the driving wheels increases the tire rolling resistance, and hence, the actual horsepower required to drive the vehicle on the chassis dynamometer.

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* N. Ostrouchov, "Effects of. Cold Weather on Motor Vehicle Emissions and Fuel Consumption - II", SAE Paper 790229, 1979.

If the EPA "cookbook" technique is used to determine the PAU setting, these losses are uncompensated as the present formula does not differentiate between RWD and FWD vehicles. Although coastdown techniques correct this situation somewhat, the FWD vehicle is still penalized. This is because the PAU setting is determined for tractive effort at 50 mph during the coastdown procedure. At speeds below 50 mph the FWD vehicle must still overcome a greater load on the dynamometer than an equivalent RWD vehicle. This is because rolling resistance is the dominant force at low speeds, while aerodynamic drag is more important at high speeds. Since about 75 percent of the mileage in the EPA test is accumulated below 50 mph, the FWD vehicle suffers a net fuel economy penalty in the FTP compared to the RWD vehicle; this would translate into decreased shortfall for FWD vehicles in comparison to RWD vehicles.

A second, possibly minor, effect which could reduce the shortfall of FWD vehicles relative to RWD vehicles is the influence of the cooling fan during the FTP test. Since the vehicle is stationary during the test, cooling air is provided by an external fan. This fan operates at constant speed and does not provide adequate cooling air at higher vehicle speeds. Most FWD vehicles have electric fans which are controlled thermostatically; these fans remain on during much of the FTP, because of the inadequate external cooling, unlike the real world situation. The electrical power absorbed by the cooling fan is supplied by the engine through the alternator. This power requirement lowers the fuel economy on the FTP relative to "on-road" conditions, resulting in decreased shortfall for FWD vehicles. RWD vehicles, a majority of which employ engine driven fans, do not have this difference in operating mode between FTP and "on-road" conditions. While the effect of the cooling fan is believed not as significant as the effect of tire loading, the cooling fan does make a contribution to shortfall reduction of FWD vehicles relative to RWD vehicles.

Diesel

Diesel engines differ markedly from spark ignition (gasoline) engines in their fuel delivery systems and the type of combustion employed. These principal technological differences could account for decreased shortfall in comparison to spark ignition engines. The reasons are as follows:

(1) The fuel injection system in the Diesel engine is factory calibrated to tight tolerances and sealed at the factory. Spark ignition engines on the other hand, have carburetors where the user can adjust the idle air/fuel ratio and the choke. As detailed earlier, EPA has found that a large majority of spark ignition engines are maladjusted to richer air/fuel ratios, leading to increased shortfall. Diesels on the other hand, are rarely maladjusted.

(2) In Diesel engines, the fuel is injected directly into the cylinder head, unlike carburetted S.I. engines where fuel is generally distributed via an intake manifold to the individual cylinders. At low ambient temperatures, Diesel engines need very little enrichment in comparison to an S.I. engine, where extra fuel is needed to ensure adequate vaporization and transport of fuel to the cylinders.

(3) Diesel engines are less sensitive to transient and non-FTP driving modes than carburetted S.I. vehicles in that the fuel consumption changes are less dramatic. This is due to two reasons: (a) the Diesel consumes very little fuel at idle in comparison to an S.I. engine (up to 70 percent less). Thus, extended idling, common in inner city driving, has a much smaller impact on the fuel consumption of Diesels than of S.I. engines; (b) transient operation such as sharp accelerations and decelerations not encountered on the FTP increase fuel consumption dramatically for an S.I. engine but not as much for a Diesel engine. A carburetted S.I. engine has very poor transient air/fuel ratio control and requires special devices such as acceleration enrichment pumps and deceleration fuel shutoffs to

control the transient air/fuel ratio. Diesels, on the other hand, use an accurate system of fuel metering where transient operation does not disturb the combustion process as much.

The combined effect of reduced tampering, lower enrichment at cold ambients, and decreased sensitivity to variations in driving cycle should reduce the shortfall for Diesel engines in comparison to S.I. engines.

III. D. 2. Technology-specific In-use Data

Against the background above, which theorizes why some advanced technologies should have lower shortfall behavior, we can now examine what actual data reveal.

Figure III.D-1 shows the shortfall characteristics of a number of vehicle technologies expressed as the ratio of road gallons per mile to EPA 55/45 gallons per mile, plotted against the EPA 55/45 MPG (this ratio is the same as EPA MPG/Road MPG).

The slanted lines are regression lines for three technology subclasses of vehicles: all are rear wheel drive, carbureted (gasoline) cars. The topmost line, labeled "Automatic" consists almost completely of standard (non-lockup or overdrive) automatics, while the "Manual" line represents just that. The band around the Manual line is the 95% confidence interval. The 95% confidence interval for Automatics is within the width of the line.

The line labeled "Auto-lockup and/or O/D" has been added to the chart on the basis of a recent finding* that automatic overdrive gives a shortfall between that of manuals and standard automatics. The assumptions that this line has a slope parallel to the other two lines, and that it also represents lockup automatics, whether or not overdriven, are our own assumptions.

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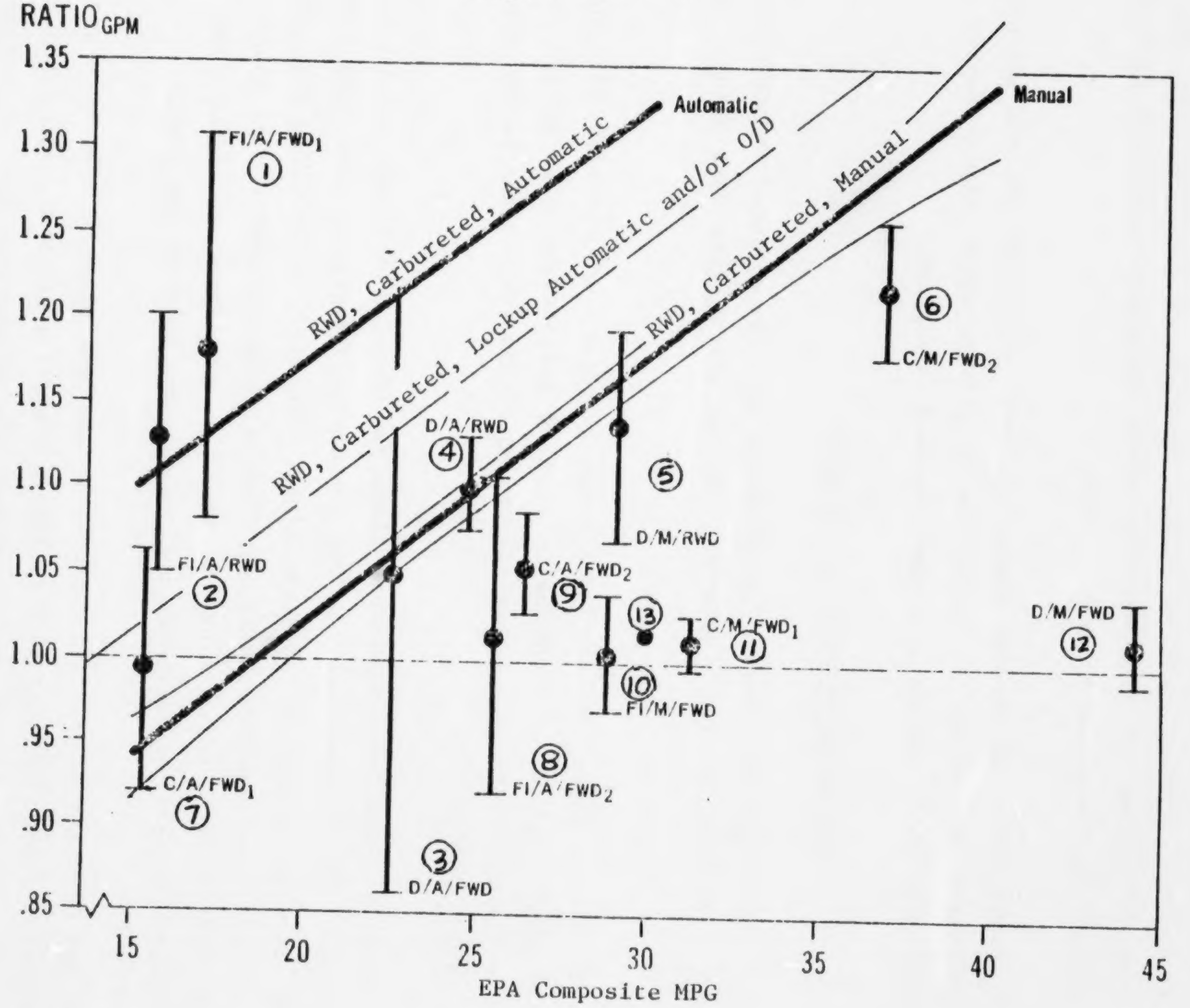
* South, "1978 to 1980 Ford On-Road Fuel Economy", SAE Paper 810383, February 1981.

Figure III. D-1

Impact of Technology on Shortfall
1978–1980 CARS



The spots and vertical bands on the figure require additional explanation. Each spot represents a particular technology, and the vertical bands span the 95% confidence intervals. For some technologies, these intervals are large because the sample sizes are small. The technology descriptions are:

Fuel System: FI = Fuel injected gasoline
C = Carbureted gasoline
D = Diesel

Transmission: A = Automatic
M = Manual

Drive: FWD = Front
RWD = Rear

The subscripts for some groups designate two inherently different subsets of a given technology. This becomes obvious when looking at table III.D-1, which gives the number of cars, and model types, included in each spot.

TABLE III. D-1

EXPLANATION OF FIGURE III. D-1

Technology Group	No. Cars	Models Included
(1) FI/A/FWD1	8	All Eldorados
(2) FI/A/RWD	14	13 Sevilles + 1 BMW
(3) D/A/FWD	2	Toronados
(4) D/A/RWD	191	Half GM, rest Mercedes & Peugeots
(5) D/M/RWD	40	39 Peugeots, 1 Mercedes
(6) C/M/FWD2	90	Fiestas & Japanese, all 1978 models
(7) C/A/FWD1	26	All GM: Rivieras, etc.
(8) FI/A/FWD2	5	Rabbits & Foxes
(9) C/A/FWD2	83	78-79 Japanese, Omnis, 1980 X-cars
(10) FI/M/FWD	73	Rabbits, Foxes, Sciroccos
(11) C/M/FWD1	184	Same as (6) plus Omnis, all 1979's
(12) D/M/FWD	72	Rabbits & Dashers
(13) C/M/ FWD1	411	1980 model Fiestas

Interpretation

The following can be gleaned from figure III.D-1 and table III.D-1:

- the behavior of the eight Eldorados in set (1) is anomalous.
- Fuel injection makes no significant difference in shortfall, compared to carbureted versions of similar vehicles.
- The high shortfall for the 90 cars in set (6) can be attributed to the 1978 test procedure, not to the cars themselves; nearly 600 of the same types of cars (but 1979-80 models) included in sets (11) and (13) show no such high average shortfall. For all three sets, (6), (11) and (13), average road MPG is consistently about 30; they were rated by the 1978 test at about 36, and by the 1979-80 test at about 31.
- Rear wheel drive Diesels have essentially the same shortfall as RWD manual gasoline cars.
- Transmission type makes no significant difference in shortfall for front wheel drive cars.
- The location of set (12), the VW front wheel drive Diesels, on the map would appear to be due to their front wheel drive rather than their "Dieselity".
- The bottom line for all of this is that these data suggest four distinguishable technology groupings, each with its own shortfall algorithm:

Front wheel drives, $1/R = 1.02/E$

RWD Manuals and Diesels, $1/R = 0.70/E + 0.016$

RWD Automatics, lockup or O/D, (gasoline) $1/R = 0.77/E + 0.016$

RWD Std. automatic (gasoline) $1/R = 0.85/E + 0.016$

where R = Road MPG and
E = EPA 55/45 MPG

Implication

When unique shortfall behaviors of specific technology strata are accounted for, time trends in aggregated fleet shortfalls can result from time changes in the mix of the various technologies. As an example, this type of analysis was done for Chrysler Corporation, who has changed from almost entirely "conventional" vehicle technology in 1975 to almost entirely "advanced" vehicle technology in 1981. Table III.D-2 shows the results. In the earlier years, we would expect increasing shortfall for the conventional part of Chrysler's fleet simply because the shortfall algorithm for these vehicles is MPG dependent, and overall fleet MPG is increasing. In fact, the calculated shortfall for conventional vehicles continues to worsen through 1981. As advanced technologies increase to significant market penetrations in the later years, however, their lower shortfall characteristic influences overall fleet behavior more and more, and aggregate fleet shortfall decreases.

Understanding now the significant role of vehicle technology changes in the shaping of time trends in fuel economy shortfall, let us compare technology specific calculated shortfalls for the entire fleet of manufacturers with the latest observed shortfalls, in table III.D-3.

Table III. D-2

Example of Variation in Calculated, Technology-Specific In-Use FE Shortfall (Chrysler Corp. Domestic Fleet)

Model Year	EPA MPG	Shortfall for RWD. Automatics (Conventional Technology)	% Use of Advanced Technology *	Fleet Shortfall
1975	14.7	- 7.7%	3%	- 7.6%
1976	15.9	- 9.2%	6%	- 9.0%
1977	15.7	- 9.0%	8%	- 8.9%
1978	17.8	-11.0%	12%	-10.3%
1979	19.8	-12.4%	24%	-10.7%
1980	20.0	-12.3%	88%	- 5.5%
1981	25.6	-14.3%	96%	- 5.1%

(*) Manual or lockup transmissions, overdrive, front wheel drive.

Table III. D-3

Similarity Between Observed Fleet Shortfall and Calculated Technology-Specific Shortfall (All Manufacturers)

Model Year	Observed Fleet Shortfall[1]	Calculated Technology Specific Fleet Shortfall[2]	Federal Emission Stds.[3]
1975	-8.9%	-7.2%	1.5/15/3.1
1976	-9.4%	-9.6%	1.5/15/3.1
1977	-15.4%	-10.6%	1.5/15/2.0
1978	-15.0%	-11.7%	1.5/15/2.0
1979	-10.2%	-11.5%	1.5/15/2.0
1980	- 3.1%(4)	-10.4%	.41/7/2.0
1981	---	- 9.7%	.41/3.4/1.0

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(1) From Contractor analysis (EEA), January 1981 (unpublished)

(2) Calculated using only technology-specific shortfall behavior, no model year dependence assumed.

(3) HC/CO/NOx grams per mile.

(4) Sample size much smaller than prior model years.

Note the parallel increasing/decreasing trends for the observations and the calculations. Three "step changes" in observed shortfall are not fully explained satisfactorily by the technology-specific theory: the six percent increase in shortfall from 1976 to 1977, the five percent decrease from 1978 to 1979, and the seven percent decrease from 1979 to 1980.

Taking the second of these first, there was no change in emission standards between 1978 and 1979, so the five percent shortfall decrease cannot be related to emissions effects. As mentioned earlier, loopholes in the EPA test procedures were closed in 1979, and we attribute this improvement in shortfall to the test procedure.

The 1976 to 1977 shortfall increase came simultaneously with a tightening of the NOx standard from 3.1 to 2.0 grams per mile, and could be concluded to be an adverse by-product of the more stringent NOx standard.

In the case of the 1979 to 1980 improvement in observed shortfall, there was at the same time a tightening of the HC and CO (but not NOx) standards, so it could be concluded in this case that reduced shortfall is a beneficial by-product of the more stringent HC and/or CO standards.

The HC/CO conclusion relationship is less strong than the NOx conclusion, because 1980 data used for this study represented a much smaller sample size.

A test case for the premise that tighter NOx control adversely affects shortfall will be the in-use data from 1981 model cars, as 1981 NOx is cut in half from the 1980 level. If a relationship exists between shortfall and the NOx standard change, it should certainly appear in 1981 cars. Unfortunately, there are no 1981 in-use fuel economy data currently available.

SECTION IV

IV. Data Analysis

The computer data bases used to support the analyses for this document were derived from two EPA sources; the Emission Factors data base, and the Certification Division data base which includes tests performed by EPA and by the individual manufacturers. From these sources, three data bases were generated for use in this study. The data bases in this study will be referenced as the EF, CERT/EPA and CERT/MFR data bases respectively. They only include data for vehicles tested under the 1975 Federal Test Procedure (FTP) and the EPA Highway Fuel Economy Test Procedure (HFET).

Certification records used to create the CERT/EPA and CERT/MFR data bases were gathered from five certification data bases. These include VEHSUM, CERTESTSUM, and DFRSLTS, which are part of the MICRO Information System, and files 1200D and 1202D-MFR (as they appeared on February 7, 1981). The VEHSUM file contains vehicle descriptions taken from the vehicle identification sheet. CERTESTSUM includes emission test results and other pertinent information from the test data sheet. Engine family deterioration factors came from DFRSLTS. 1200D included bag data and 1202D-MFR included information on whether tests were performed at high altitude or not.

The data in CERTESTSUM comes from two sources; a) tests run at the EPA emissions laboratory and b) tests performed at the manufacturers' facilities. The CERT/EPA data base, which was created specifically to support this report, is a compilation of selected information from the five Certification Division data bases discussed above, but only for vehicles which were tested at EPA. Likewise, the CERT/MFR data base was limited to vehicles tested at the manufacturers' facilities. The information selected for inclusion in the CERT/EPA and CERT/MFR files is discussed below.

From the file VEHSUM, all vehicles with a Car Line Code* of less than 50,000 were selected, except those whose Sales Class* was Both Trucks, California Trucks, or Federal Trucks. The object was to select only light duty vehicles.

The test results used from CERTESTUM were restricted to those gathered under the FTP and the HFET. Tests with Certification Test Dispositions* of VOID, NEWTEST and ZEROMILE were not included in the CERT/EPA and CERT/MFR data bases. For the FTP, the Test Types* included were emission data tests, durability tests, and fuel economy tests. For the highway fuel economy test procedure, only emission data tests and fuel economy tests were used.

The resulting data set from CERTESTSUM was then joined to the resulting data set from the VEHSUM files. They were matched by Internal Vehicle Number* and by Version Number*. In order to eliminate duplicate test results in the new data bases, carryover data were assigned to a single model year which corresponds to the last model year the data were used.

Using information from the certification data files 1200D and 1202D-MFR, high altitude tests were removed, and bag data for the EPA tests were added to the new data base. Bag data were not available for manufacturers' tests. This data base was then segregated into the CERT/EPA and EF files. Table IV-1 lists the field names which were included in the CERT/EPA and EF files. The CERT/MFR file was identical to the CERT/EPA file except that the CERT/MFR file did not contain bag emissions data.

Combined fuel economy values were calculated for each vehicle which had both FTP and HFET data. The objective was to calculate a combined fuel economy value for each vehicle configuration for which both urban and highway miles/gallon (mpg) data were available. A method was selected to achieve

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* These are field names for the data base. Explanations of these terms can be found in the August 28, 1980 letter from Robert E. Maxwell, Director, Certification Division of EPA, to light-duty motor vehicle manufacturers. This letter transmitted the Supplement to the Application Format for Certification of Light-Duty Motor Vehicles, 1981 Model Year.

Table IV-1

Information Contained in the Data Bases Used for This Study

DATA BASE VARIABLES(FIELDS) SUMMARY ("X" MEANS THE VARIABLE IS AVAILABLE)

DATA BASE	CERT-EPA			EMISSION FACTORS (EF)										
*SITE	75-			HS									LA3W	RMSF
VAR NAME / YEAR	79	80	81	79	79	78	77	76	75	74	73	72	79	77
B1.HC (BAG 1 HC)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B1.CO (BAG 1 CO)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B1.NOX (BAG 1 NOX)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B2.HC (BAG 2 HC)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B2.CO (BAG 2 CO)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B2.NOX (BAG 2 NOX)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B3.HC (BAG 3 HC)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B3.CO (BAG 3 CO)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B3.NOX (BAG 3 NOX)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FTPHC (FTP HC)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FTPCO (FTP CO)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FTPNOX (FTP NOX)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
UMPG (URBAN MPG)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
HMPG (HWY MPG)	X	X	X	X	X	X	X	X	X	X			X	
CMPG (COMB MPG)	X	X	X	X	X	X	X	X	X	X			X	
FEHC (HWY HC)	X	X	X	X	X	X	X	X	X	X			X	
FECO (HWY CO)	X	X	X	X	X	X	X	X	X	X			X	
FENOX (HWY NOX)	X	X	X	X	X	X	X	X	X	X			X	
SITE (TEST SITE)				X	X	X	X	X	X	X	X	X	X	X
VEH. (VEH. NO.)				X	X	X	X	X	X	X	X	X	X	X
TEST (TEST SEQ.)				X	X	X	X	X	X	X	X	X	X	X
FTPBP (FTP BARO. P.)				X	X	X	X	X	X	X	X	X	X	X
ODOM,MILE	X	X	X	X	X	X	X	X	X	X	X	X	X	X
FEBP (HWY BARO. P.)				X	X	X	X							
MAKE (MAKE OF AUTO)				X	X	X	X	X	X	X	X	X	X	X
MFR,MFG(MANUF.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MDYR,MYR(MODEL YEAR)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
MODL,MDL(MODEL)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
DISP,CID	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VTRN,TRAN(TRANSM)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
#BBL,CARB(# OF BBL.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
#CYL (# OF CYLIN.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
VNRT,INER(INERTIA WT.)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ADHP,HP(ACTUAL DYNO HP)	X	X	X	X	X	X	X	X	X	X	X	X	X	X
AIR.INJ(AIR INJECTED?)				X	X	X	X	X	X	X			X	X
CATA (CATALYST)				X	X	X	X	X	X	X			X	X
THER (THERMAL REACTOR)				X	X	X	X	X	X	X			X	X
ENFM,ENFY(ENG FAMILY)	X	X	X	X	X	X	X	X	X				X	X
EGR								X	X	X				X

NOTE----- *SITE: HS = HOUSTON , LA3W = LA 3W CAT , RMSF = RESTORATIVE MAINT SAN FRAN.

Table IV-1 (con't)

DATA BASE VARIABLES(FIELDS) SUMMARY ("X" MEANS THE VARIABLE IS AVAILABLE)

DATA BASE	CERT-EPA			EMISSION FACTORS (EF)										
#SITE	75-			HS									LA3W	RMSF
VAR NAME / YEAR	79	80	81	79	79	78	77	76	75	74	73	72	79	77
MAL.DISP(MAL ADJ DISP)				X	X	X	X	X	X				X	X
AXLR,AXRA(AXLE RATIO)	X	X	X	X	X	X	X						X	
MODI (ENG MODIFICATION)														X
PCV														X
TIMING														X
INT# (INTERNAL NO.)	X	X	X											
VRSN (VERSION)	X	X	X											
VID (VEH. IDENT.)	X	X	X											
CLIN (CAR LINE)	X	X	X											
OVDR (OVERDRIVE)	X	X	X											
BORE	X	X	X											
STRK (STROKE)	X	X	X											
RTHP (RATED HP)	X	X	X											
ETYP (ENG. TYPE)	X	X	X											
#CRB (NO. OF CARBS)	X	X	X											
FIN (FUEL INJ.)	X	X	X											
CMPR (COMP. RATIO)	X	X	X											
N/VR (N/V RATIO)	X	X	X											
ECS1 (EM CONT SYS 1)	X	X	X											
ECS2 (EM CONT SYS 2)	X	X	X											
ECS3 (EM CONT SYS 3)	X	X	X											
ECS4 (EM CONT SYS 4)	X	X	X											
ECS5 (EM CONT SYS 5)	X	X	X											
FTYP (FUEL TYPE)	X	X	X											
SACL (SALES CLASS)	X	X	X											
VSS (SHIFT SPEED CODE)	X	X	X											
ENCD (ENG CODE)	X	X	X											
DFV1 (DURA FAC VEH)	X	X	X											
TRBO (TURBOCHARGED)	X	X	X											
VTYP (VEH TYPE)	X	X	X											
RCNO (RUNNING CHANGE #)	X	X	X											
CRCD (CRITICAL CODE)	X	X	X											
TNUM (TEST NUMBER)	X	X	X											
TTYP (TEST TYPE)	X	X	X											
RCHG (RUNNING CHANGE)	X	X	X											
TPRO (TEST PROCEDURE)	X	X	X											
RTST (RETEST CODE)	X	X	X											
ADHP (ACTUAL DYNO HP)	X	X	X											
CTD (CERT TEST DISP.)	X	X	X											
FED (F.E. TEST DISP)	X	X	X											
TAYR (TEST ACTIVE YR)	X	X	X											
ETW (EQUIV TEST WT)	X	X	X											

this, while simultaneously attempting to avoid combining city and highway data for different configurations of the same vehicle. The last four digits of the city and highway test numbers were compared. Those test numbers which were within ± 3, for vehicles having the same internal vehicle number and version number, were used in calculating the combined fuel economy value.

This method of "pairing" city and highway tests allows more than one combined fuel economy value to be generated for vehicles which had more than one set of paired tests.

EPA's emission factors data base included data on vehicles from 1972 thru 1981. The EF data base, which was also created specifically to support this report, included information selected from EPA's emission factors data base. Table IV-1 lists the field names which were included in the EF file. Again, only FTPs and HFETs were used. Other tests such as inspection and maintenance tests and steady state tests were not used.

IV. A. Two Variable Linear Regressions

This was the initial step in a series of plotting and regression exercises. Three large data bases (CERT/EPA, CERT/MFR and EF) were used in this work.

First, two dimensional scatter plots of fuel economy and emissions for each of the following were generated.

1) UMPG* versus FTPHC**
2) UMPG versus FTPCO**
3) UMPG versus FTPNOx**
4) UMPG versus FEHC***
5) UMPG versus FECO***
6) UMPG versus FENOx***
7) HMPG* versus FTPHC
8) HMPG versus FTPCO
9) HMPG versus FTPNOx
10) HMPG versus FEHC
11) HMPG versus FECO
12) HMPG versus FENOx
13) CMPG* versus FTPHC
14) CMPG versus FTPCO
15) CMPG versus FTPNOx
16) CMPG versus FEHC
17) CMPG versus FECO
18) CMPG versus FENOx

---

*UMPG, HMPG, and CMPG respectively mean urban fuel economy as measured on the 1975 Federal Test Procedure (FTP), highway fuel economy as measured on the EPA highway test and composite fuel economy as calculated by EPA from urban and highway economy respectively.

**FTPHC, FTPCO, and FTPNOx mean HC, CO, and NOx emissions, respectively, as measured on the 1975 FTP.

***FEHC, FECO, and FENOx mean HC, CO, and NOx emissions, respectively, as measured on the EPA highway test.

For the sake of brevity, these are called "the 18" plots. These 18 plots were generated for each of the three data bases for all the data in each data base. A total of 54 plots were generated.

There was no apparent linear or other relationship between any of the two variables. Some of the plots are included as appendix 4 to this report.

The various plots that were generated were not totally adequate for visualizing lines or curve shapes because multiple points in one spot appear as a number (or x which means 10 or more points at the same spot) which is difficult to visually weight compared to single points. Linear regressions were performed that corresponded to each of the plots. A summary of the regressions is presented in table IV. A-1 through table IV. A-3.

Summary

There are several items of interest that can be deduced from these tables. First, there is no correlation for any of the regressions as evidenced by values of r-squared which always have a zero as the first digit to the right of the decimal point. Second, the slopes of the regression lines (COEFF in the tables) are consistently negative except for occasional, positive values for HC and CO as measured on the highway fuel economy test. Negative slopes mean that, as the emissions increase, the fuel economy decreases. Positive slopes mean, as emissions increase, fuel economy increases. The final item of interest is that highway HC and CO emissions are not regulated.

No readily apparent linear or other relationship between exhaust emissions and fuel economy is seen at this level of analysis. Clearly, no negative impact on fuel economy due to emissions can be identified in these data. There may be several reasons for this. These reasons include a lack of stratification of the data and the effects of other variables on fuel economy. Other approaches used later will be improved in some areas, but by necessity the number of data points available for analysis will be reduced with increasing stratification.

Table IV. A-1

Two Variable Linear Regressions Using Certification Data From the EPA Laboratory

```
                                      CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY.
                                      ---------------------------------------------------------
                                        FILE:  CERT/EPA          FEB. 27, 1981     PAGE NO.  1

     <------- CATEGORICAL VARIABLES ------->                 ACTUAL* TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)   SIZE    SIZE    COEFF    CONST   R-SQ    STD.ERR   <-------REMARKS -------->

  1                                          UMPG   FTPHC    4605    5753   -0.5468   18.814 0.00092 5.7657
  2                                          UMPG   FTPCO    4605    5753   -0.1968   19.627 0.01907 5.7131
  3                                          UMPG   FTPNOX   4605    5753   -2.2268   21.608 0.04811 5.6279
  4                                          UMPG   FEHC     2975    5753    3.0094   18.204 0.00803 5.6870
  5                                          UMPG   FECO     2975    5753    0.1799   18.395 0.00280 5.7019
  6                                          UMPG   FENOX    2975    5753   -1.0281   20.191 0.02363 5.6421
  7                                          HMPG   FTPHC    2977    5753   -0.2919   26.222 0.00012 7.7974
  8                                          HMPG   FTPCO    2977    5753   -0.2683   27.505 0.01474 7.7401
  9                                          HMPG   FTPNOX   2977    5753   -3.1631   30.389 0.04854 7.6062
 10                                          HMPG   FEHC     4123    5753    5.6186   26.001 0.01325 7.8347
 11                                          HMPG   FECO     4123    5753    0.1999   26.448 0.00179 7.8800
 12                                          HMPG   FENOX    4123    5753   -1.3075   28.623 0.01942 7.8102
 13                                          CMPG   FTPHC    2977    5753   -0.3914   21.464 0.00033 6.4044
 14                                          CMPG   FTPCO    2977    5753   -0.2300   22.498 0.01606 6.3538
 15                                          CMPG   FTPNOX   2977    5753   -2.5551   24.757 0.04694 6.2533
 16                                          CMPG   FEHC     2975    5753    3.8268   20.835 0.01032 6.3733
 17                                          CMPG   FECO     2975    5753    0.1933   21.109 0.00257 6.3982
 18                                          CMPG   FENOX    2975    5753   -1.1262   23.073 0.02252 6.3339
```

---

* Actual size is less than total size in this and subsequent computer outputs due to the method used in construction of the data base. In general the difference between actual and total size is an indicator that not all urban tests have paired highway tests and that not all highway tests have paired urban tests. This difference is not an indicator that data were ignored or deleted for any reason.

Table IV. A-2

Two Variable Linear Regressions Using Data From the Emission Factors (In-Use) Program

```
                        EMISSION FACTOR MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                        ------------------------------------------------------------
                          FILE:  2614D-EF(ALL)      MAR. 02, 1981     PAGE NO.  1

      <------- CATEGORICAL VARIABLES ------->                 ACTUAL  TOTAL
CASE MDYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)  SIZE    SIZE    COEFF     CONST   R-SQ   STD.ERR   <-------REMARKS -------->

  1                                          UMPG   FTPHC   8987    8987   -0.2666   16.218 0.04230 4.3084
  2                                          UMPG   FTPCO   8987    8987   -0.3494   16.718 0.08816 4.2040
  3                                          UMPG   FTPNOX  8923    8987   -0.6145   17.156 0.05339 4.2879
  4                                          UMPG   FEHC    6615    8987   -0.3909   16.313 0.00980 4.3758
  5                                          UMPG   FECO    6353    8987   -0.2959   16.360 0.01282 4.4133
  6                                          UMPG   FENOX   6616    8987   -0.3973   17.142 0.02551 4.3407
  7                                          HMPG   FTPHC   6616    8987   -0.4714   23.596 0.02841 6.3079
  8                                          HMPG   FTPCO   6616    8987   -0.5040   23.991 0.04939 6.2395
  9                                          HMPG   FTPNOX  6552    8987   -1.0881   25.186 0.04889 6.2503
 10                                          HMPG   FEHC    6615    8987   -0.6566   23.127 0.01305 6.3581
 11                                          HMPG   FECO    6353    8987   -0.5447   23.252 0.02050 6.3977
 12                                          HMPG   FENOX   6616    8987   -0.6451   24.460 0.03175 6.2971
 13                                          CMPG   FTPHC   6616    8987   -0.3978   19.214 0.03237 4.9756
 14                                          CMPG   FTPCO   6616    8967   -0.4333   19.567 0.05843 4.9082
 15                                          CMPG   FTPNOX  6552    8987   -0.8058   20.312 0.04297 4.9527
 16                                          CMPG   FEHC    6615    8987   -0.4816   18.779 0.01124 5.0300
 17                                          CMPG   FECO    6353    8987   -0.3797   18.850 0.01595 5.0691
 18                                          CMPG   FENOX   6616    8987   -0.4815   19.779 0.02832 4.9861
```

Table IV. A-3

Two Variable Linear Regressions Using Certification Data From Vehicle Manufacturers

```
                                       CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                                       ---------------------------------------------------------
                                         FILE:  CERT/MFR         FEB. 27, 1981    PAGE NO.  1

      <------- CATEGORICAL VARIABLES ------->             ACTUAL  TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)  SIZE   SIZE    COEFF    CONST   R-SQ   STD.ERR   <--------REMARKS -------->

  1                                          UMPG   FTPHC   9786  10425  -2.4196   20.134 0.01156 5.5006
  2                                          UMPG   FTPCO   9786  10425  -0.2674   20.344 0.02429 5.4650
  3                                          UMPG   FTPNOX  9786  10425  -0.9418   20.260 0.00654 5.5145
  4                                          UMPG   FEHC    5072  10425   1.3907   19.324 0.00079 5.6312
  5                                          UMPG   FECO    5072  10425  -0.3842   19.476 0.00012 5.6330
  6                                          UMPG   FENOX   5072  10425  -0.6959   20.328 0.00910 5.6077
  7                                          HMPG   FTPHC   5087  10425  -2.2697   28.391 0.00787 7.3664
  8                                          HMPG   FTPCO   5087  10425  -0.4437   29.544 0.03971 7.2472
  9                                          HMPG   FTPNOX  5087  10425  -2.6842   30.645 0.03305 7.2723
 10                                          HMPG   FEHC    5710  10425   1.6638   27.361 0.00074 7.4021
 11                                          HMPG   FECO    5710  10425  -0.1514   27.641 0.00129 7.4000
 12                                          HMPG   FENOX   5710  10425  -0.8867   28.646 0.00858 7.3700
 13                                          CMPG   FTPHC   5087  10425  -2.1011   23.169 0.00951 6.2012
 14                                          CMPG   FTPCO   5087  10425  -0.3692   24.046 0.03874 6.1090
 15                                          CMPG   FTPNOX  5087  10425  -2.1332   24.845 0.02941 6.1386
 16                                          CMPG   FEHC    5072  10425   1.6749   22.218 0.00093 6.2289
 17                                          CMPG   FECO    5072  10425  -0.7912   22.429 0.00042 6.2305
 18                                          CMPG   FENOX   5072  10425  -0.7872   23.363 0.00952 6.2021
```

IV. B. Two Variable Linear Regressions with Stratification by Model Year

Various stratifications of the data analyzed in section IV. A of this report could be done. Intuitively,the stratification of choice appears to be by emission control system; however, data base limitations would not permit this stratification without greatly reducing the available data or without modifying the available data. The stratification chosen was by vehicle model year (or for certification data by test active year). This stratification was accomplished with minor losses of data. Stratification by emission control system was accomplished later by data modification (see section IV. H).

Plots were generated for each of the three data bases for each of the 18 emission versus fuel economy relationships for each model year. Again, no linear or other relationships between fuel economy and emissions were seen. Those plots were not reproduced for inclusion in this report.

Linear regressions were again run using the 18 emission and fuel economy variables for each of the 3 data bases stratified by model year. The results of these regressions are presented here in table IV. B-1 through table IV. B-3. In the following discussion of these results, only cases where sample size ("actual size" in the tables) was greater than or equal to 25 are considered.

Correlation

Of the 126 cases (144 minus 18 cases with less than 25 data points) generated for the CERT/EPA data base, r-squared did not exceed 0.100 in any case.

A total of 135 cases were generated for the Emission Factors data base. r-squared exceeded 0.100 in 9 of these cases. The range of r-squared was from 0.12 to 0.24 for those 9 cases. The emission variable was CO as measured on the 1975 FTP in each case. The fuel economy variables were urban fuel economy for model years 1966 through 1971 and model year 1978,

Table IV. B-1

Two Variable Linear Regression Results Using Data From the EPA Laboratory Stratified by Model Year

```
                         CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                         ----------------------------------------------------------
                          FILE:  CERT/EPA          FEB. 27, 1981    PAGE NO.  1

      <------- CATEGORICAL VARIABLES ------->                ACTUAL  TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)   SIZE   SIZE    COEFF    CONST   R-SQ  STD.ERR   <--------REMARKS -------->

  1   75                                      UMPG  FTPHC      77     79  -0.9647  14.887 0.00413 4.5903
  2   76                                      UMPG  FTPHC     699    712   2.4851  15.413 0.02918 5.0591
  3   77                                      UMPG  FTPHC    1021   1270   3.1122  15.216 0.04120 5.1099
  4   78                                      UMPG  FTPHC    1010   1264   2.5999  16.465 0.01702 5.7337
  5   79                                      UMPG  FTPHC     730    970   1.2941  18.598 0.00488 5.3140
  6   80                                      UMPG  FTPHC     597    804   1.9355  20.245 0.00393 5.2231
  7   81                                      UMPG  FTPHC     459    638  -9.4330  24.485 0.01550 6.1586
  8   82                                      UMPG  FTPHC      12     16  14.6460  22.572 0.36566 1.3838
  9   75                                      UMPG  FTPCO      77     79  -0.2156  15.574 0.02694 4.5375
 10   76                                      UMPG  FTPCO     699    712   0.1560  16.099 0.01116 5.1059
 11   77                                      UMPG  FTPCO    1021   1270   0.8463  16.851 0.00004 5.2184
 12   78                                      UMPG  FTPCO    1010   1264   0.5813  17.847 0.00002 5.7831
 13   79                                      UMPG  FTPCO     730    970  -0.2370  20.744 0.02657 5.2558
 14   80                                      UMPG  FTPCO     597    804  -0.1216  21.120 0.00950 5.2085
 15   81                                      UMPG  FTPCO     459    638  -1.0629  24.692 0.04405 6.0686
 16   82                                      UMPG  FTPCO      12     16   0.3123  24.973 0.02966 1.7115
 17   75                                      UMPG  FTPNOX     77     79  -2.1416  18.260 0.08407 4.4023
 18   76                                      UMPG  FTPNOX    699    712  -0.2024  17.432 0.00056 5.1332
 19   77                                      UMPG  FTPNOX   1021   1270  -1.5465  19.115 0.01587 5.1770
 20   78                                      UMPG  FTPNOX   1010   1264  -2.3144  21.155 0.02502 5.7103
 21   79                                      UMPG  FTPNOX    730    970  -0.1435  19.275 0.0     5.3270
 22   80                                      UMPG  FTPNOX    597    804   0.6743  20.680 0.00004 5.2333
 23   81                                      UMPG  FTPNOX    459    638   2.2990  21.075 0.01375 6.1640
 24   82                                      UMPG  FTPNOX     12     16   5.2000  22.751 0.14608 1.6056
 25   75                                      UMPG  FEHC       53     79  -1.0659  15.033 0.00139 4.9253
 26   76                                      UMPG  FEHC      499    712   5.7056  16.028 0.06505 4.8766
 27   77                                      UMPG  FEHC      602   1270   4.4349  16.414 0.03163 5.0628
 28   78                                      UMPG  FEHC      654   1264   5.5106  17.174 0.01904 5.5784
 29   79                                      UMPG  FEHC      470    970   8.0557  18.405 0.05812 5.3372
 30   80                                      UMPG  FEHC      399    804  17.4420  19.584 0.03709 5.2256
 31   81                                      UMPG  FEHC      291    638  -8.3948  22.942 0.00524 6.0643
 32   82                                      UMPG  FEHC        7     16  29.4920  23.741 0.40186 1.1835
 33   75                                      UMPG  FECO       53     79  -0.5268  15.413 0.01979 4.8798
 34   76                                      UMPG  FECO      499    712   0.9041  16.177 0.06846 4.8677
 35   77                                      UMPG  FECO      602   1270   0.2441  16.721 0.01049 5.1178
 36   78                                      UMPG  FECO      654   1264   0.4111  17.356 0.01789 5.5817
 37   79                                      UMPG  FECO      470    970   0.2103  19.152 0.00535 5.4847
 38   80                                      UMPG  FECO      399    804   0.4229  20.430 0.00198 5.3200
 39   81                                      UMPG  FECO      291    638  -0.8565  22.902 0.01522 6.0338
 40   82                                      UMPG  FECO        7     16   2.0213  24.569 0.08247 1.4658
 41   75                                      UMPG  FENOX      53     79  -0.2926  15.455 0.00311 4.9211
 42   76                                      UMPG  FENOX     499    712   0.3374  16.375 0.00331 5.0351
 43   77                                      UMPG  FENOX     602   1270  -0.5603  17.900 0.00661 5.1278
 44   78                                      UMPG  FENOX     654   1264  -0.4961  18.589 0.00356 5.6223
 45   79                                      UMPG  FENOX     470    970   0.8466  17.929 0.01073 5.4698
 46   80                                      UMPG  FENOX     399    804   0.1203  20.442 0.00024 5.3246
 47   81                                      UMPG  FENOX     291    638   1.8915  21.572 0.01386 6.0380
 48   82                                      UMPG  FENOX       7     16  11.5760  21.875 0.69915 0.8393
 49   75                                      HMPG  FTPHC      53     79   0.7283  21.366 0.00001 7.4875
 50   76
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Table IV. B-1 (con't)

Two Variable Linear Regression Results Using Data From the EPA Laboratory Stratified by Model Year

CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY

FILE: CERT/EPA FEB. 27, 1981 PAGE NO. 2

	<------- CATEGORICAL VARIABLES						------->			ACTUAL	TOTAL					
CASE	TAYR	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	XXXX	DEP(Y)	IND(X)	SIZE	SIZE	COEFF	CONST	R-SQ	STD.ERR	<-------REMARKS ------->
51	77								HMPG	FTPHC	603	1270	4.8582	21.381	0.04336	7.0975	
52	78								HMPG	FTPHC	655	1264	4.2126	22.748	0.02490	7.1732	
53	79								HMPG	FTPHC	470	970	2.2011	25.750	0.00658	7.5346	
54	80								HMPG	FTPHC	399	804	5.0576	27.689	0.00442	7.0481	
55	81								HMPG	FTPHC	291	638	-16.1820	34.987	0.02569	7.9703	
56	82								HMPG	FTPHC	7	16	9.9569	37.413	0.04686	3.2960	
57	75								HMPG	FTPCO	53	79	-0.1755	22.365	0.00685	7.4619	
58	76								HMPG	FTPCO	499	712	0.5201	21.228	0.05271	7.1089	
59	77								HMPG	FTPCO	603	1270	0.3837	23.726	0.00032	7.2553	
60	78								HMPG	FTPCO	655	1264	0.6078	24.557	0.00098	7.2606	
61	79								HMPG	FTPCO	470	970	-0.3200	28.850	0.02317	7.4715	
62	80								HMPG	FTPCO	399	804	-0.7609	31.070	0.02691	6.9680	
63	81								HMPG	FTPCO	291	638	-1.1599	33.956	0.02918	7.9560	
64	82								HMPG	FTPCO	7	16	-1.8525	42.504	0.20755	3.0054	
65	75								HMPG	FTPNOX	53	79	-2.0638	24.957	0.02988	7.3748	
66	76								HMPG	FTPNOX	499	712	-0.1682	24.552	0.00016	7.3034	
67	77								HMPG	FTPNOX	603	1270	-2.2369	27.089	0.01323	7.2083	
68	78								HMPG	FTPNOX	655	1264	-2.7885	28.860	0.02119	7.1868	
69	79								HMPG	FTPNOX	470	970	-0.8743	28.046	0.00178	7.5528	
70	80								HMPG	FTPNOX	399	804	-0.1912	29.146	0.00019	7.0631	
71	81								HMPG	FTPNOX	291	638	1.3128	30.796	0.00262	8.0641	
72	82								HMPG	FTPNOX	7	16	-10.5250	44.478	0.16395	3.0869	
73	75								HMPG	FEHC	55	79	1.1857	21.101	0.00075	7.3875	
74	76								HMPG	FEHC	512	712	9.2636	22.401	0.08063	7.0145	
75	77								HMPG	FEHC	851	1270	9.5841	23.340	0.06417	7.3233	
76	78								HMPG	FEHC	908	1264	9.5990	24.450	0.03365	7.3608	
77	79								HMPG	FEHC	710	970	12.1710	25.411	0.06635	7.0808	
78	80								HMPG	FEHC	606	804	17.8260	28.259	0.02318	7.1825	
79	81								HMPG	FEHC	470	638	-9.3569	32.298	0.00386	7.7928	
80	82								HMPG	FEHC	11	16	32.7580	38.221	0.05394	4.0747	
81	75								HMPG	FECO	55	79	-0.2885	21.589	0.00257	7.3807	
82	76								HMPG	FECO	512	712	1.4175	22.707	0.07868	7.0220	
83	77								HMPG	FECO	851	1270	0.3728	24.178	0.01098	7.5286	
84	78								HMPG	FECO	908	1264	0.6196	24.848	0.02264	7.4026	
85	79								HMPG	FECO	710	970	0.1816	26.621	0.00221	7.3200	
86	80								HMPG	FECO	606	804	-0.2046	29.320	0.0	7.2672	
87	81								HMPG	FECO	470	638	-1.0284	32.322	0.01693	7.7415	
88	82								HMPG	FECO	11	16	8.2762	38.293	0.19722	3.7535	
89	75								HMPG	FENOX	55	79	-0.2169	21.729	0.00075	7.3874	
90	76								HMPG	FENOX	512	712	0.7796	22.458	0.00846	7.2846	
91	77								HMPG	FENOX	851	1270	-0.2460	24.980	0.00060	7.5679	
92	78								HMPG	FENOX	908	1264	-0.7263	25.584	0.00004	7.4877	
93	79								HMPG	FENOX	710	970	1.5880	24.176	0.02130	7.2496	
94	80								HMPG	FENOX	606	804	0.3283	28.931	0.00095	7.2638	
95	81								HMPG	FENOX	470	638	2.1895	30.725	0.01028	7.7677	
96	82								HMPG	FENOX	11	16	19.5270	34.413	0.26174	3.5995	
97	75								CMPG	FTPHC	53	79	-0.8800	17.667	0.00202	5.7843	
98	76								CMPG	FTPHC	499	712	4.5425	16.897	0.06662	5.5949	
99	77								CMPG	FTPHC	603	1270	4.0372	17.363	0.04617	5.7076	
100	78								CMPG	FTPHC	655	1264	3.3158	18.617	0.02116	6.1368	

Table IV. B-1 (con't)

Two Variable Linear Regression Results Using Data From the EPA Laboratory Stratified by Model Year

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                      CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                      ---------------------------------------------------------
                        FILE:  CERT/EPA          FEB. 27, 1981    PAGE NO.  3

     <------- CATEGORICAL VARIABLES ------->               ACTUAL  TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)   SIZE   SIZE     COEFF    CONST     R-SQ STD.ERR   <-------REMARKS -------->

101  79                                      CMPG   FTPHC     470    970    1.7048   21.253  0.00592  6.1583
102  80                                      CMPG   FTPHC     399    804    2.9416   22.876  0.00217  5.8601
103  81                                      CMPG   FTPHC     291    638  -18.0520   29.567  0.04611  6.5661
104  82                                      CMPG   FTPHC       7     16   12.2850   27.499  0.23732  1.6164
105  75                                      CMPG   FTPCO      53     79   -0.2475   18.561  0.02276  5.7239
106  76                                      CMPG   FTPCO     499    712    0.3728   17.542  0.04309  5.6650
107  77                                      CMPG   FTPCO     603   1270    0.4982   19.208  0.00084  5.8416
108  78                                      CMPG   FTPCO     655   1264    0.3507   20.128  0.00045  6.2014
109  79                                      CMPG   FTPCO     470    970   -0.2609   23.735  0.02306  6.1049
110  80                                      CMPG   FTPCO     399    804   -0.7270   25.641  0.03562  5.7610
111  81                                      CMPG   FTPCO     291    638   -1.1704   28.164  0.04285  6.5773
112  82                                      CMPG   FTPCO       7     16   -0.8932   29.846  0.00161  1.8494
113  75                                      CMPG   FTPNOX     53     79   -1.8013   20.307  0.03807  5.6789
114  76                                      CMPG   FTPNOX    499    712   -0.3706   19.768  0.00001  5.7911
115  77                                      CMPG   FTPNOX    603   1270   -1.6855   21.863  0.01159  5.8101
116  78                                      CMPG   FTPNOX    655   1264   -2.3144   23.595  0.02002  6.1404
117  79                                      CMPG   FTPNOX    470    970   -0.2981   22.513  0.00031  6.1756
118  80                                      CMPG   FTPNOX    399    804   -0.4040   24.048  0.00123  5.8629
119  81                                      CMPG   FTPNOX    291    638    1.5035   24.868  0.00495  6.7062
120  82                                      CMPG   FTPNOX      7     16    0.8689   29.249  0.00372  1.8474
121  75                                      CMPG   FEHC       53     79   -0.3822   17.268  0.00013  5.7898
122  76                                      CMPG   FEHC      499    712    6.9418   18.356  0.07303  5.5756
123  77                                      CMPG   FEHC      602   1270    5.5638   18.783  0.03854  5.7339
124  78                                      CMPG   FEHC      654   1264    6.7633   19.656  0.02366  6.1269
125  79                                      CMPG   FEHC      470    970    9.6356   20.956  0.06592  5.9695
126  80                                      CMPG   FEHC      399    804   17.7050   22.586  0.03149  5.7734
127  81                                      CMPG   FEHC      291    638  -10.5730   26.353  0.00681  6.7000
128  82                                      CMPG   FEHC        7     16   27.9580   28.695  0.24686  1.6062
129  75                                      CMPG   FECO       53     79   -0.4927   17.725  0.01254  5.7537
130  76                                      CMPG   FECO      499    712    1.0796   18.558  0.07406  5.5726
131  77                                      CMPG   FECO      602   1270    0.2655   19.211  0.00961  5.8196
132  78                                      CMPG   FECO      654   1264    0.4461   19.935  0.01738  6.1466
133  79                                      CMPG   FECO      470    970    0.2196   21.883  0.00462  6.1623
134  80                                      CMPG   FECO      399    804    0.3307   23.481  0.00100  5.8635
135  81                                      CMPG   FECO      291    638   -1.0222   26.275  0.01773  6.6630
136  82                                      CMPG   FECO        7     16    1.4628   29.529  0.02952  1.8233
137  75                                      CMPG   FENOX      53     79   -0.2959   17.809  0.00230  5.7835
138  76                                      CMPG   FENOX     499    712    0.4637   18.658  0.00474  5.7774
139  77                                      CMPG   FENOX     602   1270   -0.5462   20.390  0.00486  5.8335
140  78                                      CMPG   FENOX     654   1264   -0.4346   21.095  0.00226  6.1937
141  79                                      CMPG   FENOX     470    970    0.9950   20.417  0.01175  6.1402
142  80                                      CMPG   FENOX     399    804    0.1765   23.393  0.00043  5.8652
143  81                                      CMPG   FENOX     291    638    1.9572   24.832  0.01214  6.6820
144  82                                      CMPG   FENOX       7     16   10.8230   26.964  0.41776  1.4123
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Tabl V.

Two Variable Linear Regression Results Using Data From the Emission Factors (In-Use) Program Stratified by Model Year

```
                    EMISSION FACTOR MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                    -----------------------------------------------------------
                      FILE:  2614D-EF(ALL)     MAR. 02, 1981    PAGE NO.  1

     <------- CATEGORICAL VARIABLES ------->                ACTUAL  TOTAL
CASE MDYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)  SIZE    SIZE    COEFF    CONST   R-SQ    STD.ERR   <--------REMARKS -------->

  1   66                                    UMPG   FTPHC     102     102  -0.2918   14.802 0.00746 3.0236
  2   67                                    UMPG   FTPHC     212     212  -0.1442   15.212 0.06997 3.2868
  3   68                                    UMPG   FTPHC     235     235  -0.1293   15.130 0.06823 2.9439
  4   69                                    UMPG   FTPHC     260     260  -0.1391   15.033 0.03326 3.0975
  5   70                                    UMPG   FTPHC     294     294  -0.2646   15.780 0.07501 3.9029
  6   71                                    UMPG   FTPHC     343     343  -0.3583   16.464 0.02524 4.9243
  7   72                                    UMPG   FTPHC     391     391  -0.2828   15.185 0.03304 4.7207
  8   73                                    UMPG   FTPHC     211     211  -0.4029   15.325 0.04529 4.2832
  9   74                                    UMPG   FTPHC      63      63  -0.6192   12.913 0.00030 4.3164
 10   75                                    UMPG   FTPHC     994     994  -0.2071   14.771 0.03153 4.0396
 11   76                                    UMPG   FTPHC    2133    2133  -0.7144   14.730 0.00102 3.7216
 12   77                                    UMPG   FTPHC    1264    1264  -0.2820   16.553 0.02057 4.2895
 13   78                                    UMPG   FTPHC     834     834  -0.3606   17.787 0.05827 4.4195
 14   79                                    UMPG   FTPHC    1448    1448  -0.3888   18.269 0.00653 4.4996
 15   80                                    UMPG   FTPHC     201     201  -1.2391   19.601 0.07153 3.2484
 16   66                                    UMPG   FTPCO     102     102  -0.2913   17.412 0.21332 2.6918
 17   67                                    UMPG   FTPCO     212     212  -0.3144   17.248 0.23857 2.9739
 18   68                                    UMPG   FTPCO     235     235  -0.2903   16.395 0.18895 2.7466
 19   69                                    UMPG   FTPCO     260     260  -0.3650   16.854 0.19260 2.8308
 20   70                                    UMPG   FTPCO     294     294  -0.5069   17.743 0.22261 3.5780
 21   71                                    UMPG   FTPCO     343     343  -0.4967   17.823 0.13749 4.6321
 22   72                                    UMPG   FTPCO     391     391  -0.3908   16.148 0.09519 4.5665
 23   73                                    UMPG   FTPCO     211     211  -0.3193   15.447 0.07490 4.2163
 24   74                                    UMPG   FTPCO      63      63  -0.2076   13.566 0.01825 4.2775
 25   75                                    UMPG   FTPCO     994     994  -0.2173   15.007 0.04222 4.0172
 26   76                                    UMPG   FTPCO    2133    2133  -0.1808   15.025 0.01855 3.6888
 27   77                                    UMPG   FTPCO    1264    1264  -0.4038   17.071 0.05447 4.2146
 28   78                                    UMPG   FTPCO     834     834  -0.5933   18.695 0.13132 4.2446
 29   79                                    UMPG   FTPCO    1448    1448  -0.3283   18.379 0.02138 4.4659
 30   80                                    UMPG   FTPCO     201     201  -0.3402   19.324 0.03827 3.3060
 31   66                                    UMPG   FTPNOX    102     102  -0.4006   14.656 0.00050 3.0341
 32   67                                    UMPG   FTPNOX    212     212  -0.1553   14.526 0.00681 3.3965
 33   68                                    UMPG   FTPNOX    235     235  -0.3354   15.735 0.05245 2.9688
 34   69                                    UMPG   FTPNOX    260     260  -0.3272   15.807 0.04661 3.0761
 35   70                                    UMPG   FTPNOX    294     294  -0.4140   16.130 0.03470 3.9870
 36   71                                    UMPG   FTPNOX    343     343  -0.8092   18.263 0.08123 4.7808
 37   72                                    UMPG   FTPNOX    391     391  -0.8385   17.675 0.09672 4.5627
 38   73                                    UMPG   FTPNOX    211     211  -0.1970   14.424 0.00490 4.3729
 39   74                                    UMPG   FTPNOX     63      63  -0.6904   14.471 0.03815 4.2339
 40   75                                    UMPG   FTPNOX    980     994  -0.2195   14.876 0.00430 4.1000
 41   76                                    UMPG   FTPNOX   2114    2133   0.2542   14.559 0.00009 3.7321
 42   77                                    UMPG   FTPNOX   1233    1264  -0.3222   16.727 0.00828 4.3313
 43   78                                    UMPG   FTPNOX    834     834  -0.7974   18.622 0.05698 4.4225
 44   79                                    UMPG   FTPNOX   1448    1448  -0.5890   18.791 0.01509 4.4802
 45   80                                    UMPG   FTPNOX    201     201  -0.1929   19.261 0.00192 3.3680
 46   74                                    UMPG   FEHC        3      63   1.8516   19.102 0.88572 0.7122
 47   75                                    UMPG   FEHC      987     994  -0.2441   14.504 0.00895 4.0827
 48   76                                    UMPG   FEHC     1869    2133  -0.6931   15.029 0.00019 3.7228
 49   77                                    UMPG   FEHC     1264    1264  -0.2297   16.130 0.00316 4.3274
 50   78                                    UMPG   FEHC      834     834  -0.3847   17.286 0.02289 4.5017
```

Table IV. B-2 (con't)

Two Variable Linear Regression Results Using Data From the Emission Factors (In-Use) Program Stratified by Model Year

```
                           EMISSION FACTOR MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                           -----------------------------------------------------------
                               FILE:  2614D-EF(ALL)     MAR. 02, 1981    PAGE NO.  2
                                                       ---------------------------
       <------- CATEGORICAL VARIABLES ------->
CASE MDYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)  ACTUAL  TOTAL
                                                             SIZE    SIZE    COEFF    CONST   R-SQ   STD.ERR   <-------REMARKS -------->
  51  79
  52  80                                     UMPG   FEHC      1447    1448   0.1417   17.814 0.00025 4.5154
  53  74                                     UMPG   FEHC       201     201  -1.7874   19.243 0.04419 3.2959
  54  75                                     UMPG   FECO         3      63   1.9628   17.574 0.99530 0.1445
  55  76                                     UMPG   FECO       963     994  -0.2447   14.642 0.01606 4.1010
  56  77                                     UMPG   FECO      1828    2133  -0.1301   15.100 0.00358 3.7397
  57  78                                     UMPG   FECO      1240    1264  -0.1500   16.144 0.00263 4.3546
  58  79                                     UMPG   FECO       819     834  -0.2883   17.262 0.01232 4.5057
  59  80                                     UMPG   FECO      1325    1448  -0.3354   18.233 0.01056 4.5880
  60  74                                     UMPG   FECO       165     201  -0.4582   19.491 0.04126 3.3081
  61  75                                     UMPG   FENOX        3      63  -3.7610   25.548 0.73873 1.0769
  62  76                                     UMPG   FENOX      987     994  -0.1383   14.752 0.00332 4.0942
  63  77                                     UMPG   FENOX     1869    2133  -0.7454   15.231 0.00123 3.7209
  64  78                                     UMPG   FENOX     1264    1264  -0.1192   16.291 0.00226 4.3294
  65  79                                     UMPG   FENOX      834     834  -0.4624   18.163 0.04446 4.4517
  66  80                                     UMPG   FENOX     1448    1448  -0.1463   18.138 0.00175 4.5104
  67  74                                     UMPG   FENOX      201     201   0.2491   18.683 0.00469 3.3633
  68  75                                     HMPG   FTPHC        3      63   2.6777   26.222 0.89085 1.1935
  69  76                                     HMPG   FTPHC      987     994  -0.2417   20.840 0.02156 5.7453
  70  77                                     HMPG   FTPHC     1869    2133  -0.2236   21.312 0.00526 5.2945
  71  78                                     HMPG   FTPHC     1264    1264  -0.4066   23.550 0.02135 6.0690
  72  79                                     HMPG   FTPHC      834     834  -0.5008   25.324 0.05433 6.3703
  73  80                                     HMPG   FTPHC     1448    1448  -0.3570   25.616 0.00242 6.8081
  74  74                                     HMPG   FTPHC      201     201  -1.6618   28.744 0.05895 4.8313
  75  75                                     HMPG   FTPCO        3      63   3.0168   21.960 0.92521 0.9880
  76  76                                     HMPG   FTPCO      987     994  -0.2556   21.124 0.02929 5.7226
  77  77                                     HMPG   FTPCO     1869    2133  -0.2842   21.599 0.02188 5.2501
  78  78                                     HMPG   FTPCO     1264    1264  -0.5214   24.134 0.04533 5.9942
  79  79                                     HMPG   FTPCO      834     834  -0.8199   26.574 0.12121 6.1409
  80  80                                     HMPG   FTPCO     1448    1448  -0.4065   25.883 0.01438 6.7672
  81  74                                     HMPG   FTPCO      201     201  -0.4164   28.336 0.02627 4.9145
  82  75                                     HMPG   FTPNOX       3      63  -8.9538   41.970 0.99640 0.2166
  83  76                                     HMPG   FTPNOX     973     994  -0.3802   21.275 0.00641 5.8078
  84  77                                     HMPG   FTPNOX    1850    2133  -0.2849   21.709 0.00541 5.3060
  85  78                                     HMPG   FTPNOX    1233    1264  -0.6128   24.103 0.01492 6.1175
  86  79                                     HMPG   FTPNOX     834     834  -1.3355   26.942 0.07726 6.2926
  87  80                                     HMPG   FTPNOX    1448    1448  -0.9813   26.793 0.01837 6.7535
  88  74                                     HMPG   FTPNOX     201     201  -0.6484   28.807 0.00994 4.9555
  89  75                                     HMPG   FEHC         3      63   3.3498   27.023 0.98589 0.4291
  90  76                                     HMPG   FEHC       987     994  -0.3849   20.567 0.01109 5.7760
  91  77                                     HMPG   FEHC      1869    2133  -0.3363   21.098 0.00225 5.3026
  92  78                                     HMPG   FEHC      1264    1264  -0.4913   23.031 0.00721 6.1127
  93  79                                     HMPG   FEHC       834     834  -0.6259   24.692 0.02929 6.4541
  94  80                                     HMPG   FEHC      1447    1448   0.2500   25.163 0.00034 6.8168
  95  74                                     HMPG   FEHC       201     201  -2.7121   28.306 0.04662 4.8629
  96  75                                     HMPG   FECO         3      63   2.9064   25.247 0.74220 1.8342
  97  76                                     HMPG   FECO       963     994  -0.4289   20.841 0.02457 5.7862
  98  77                                     HMPG   FECO      1828    2133  -0.2940   21.158 0.00897 5.3232
  99  78                                     HMPG   FECO      1240    1264  -0.3546   23.065 0.00732 6.1556
 100  79                                     HMPG   FECO       819     834  -0.6501   24.837 0.03018 6.4327
                                             HMPG   FECO      1325    1448  -0.5770   25.880 0.01381 6.8912
```

Table IV B-2 (con't)

Two Variable Linear Regression Results Using Data From the Emission Factors (In-Use) Program Stratified by Model Year

```
                    EMISSION FACTOR MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                    -----------------------------------------------------------
                       FILE:  2614D-EF(ALL)      MAR. 02, 1981     PAGE NO.  3

     <------- CATEGORICAL VARIABLES ------->                 ACTUAL  TOTAL
CASE MDYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)  SIZE    SIZE    COEFF     CONST   R-SQ   STD.ERR    <-------REMARKS -------->

 101  80                                      HMPG   FECO     165     201   -0.7032   28.751 0.04442 4.8852
 102  74                                      HMPG   FENOX      3      63   -7.4836   39.582 0.99474 0.2620
 103  75                                      HMPG   FENOX    987     994   -0.1622   20.781 0.00228 5.8017
 104  76                                      HMPG   FENOX   1869    2133   -0.9794   21.224 0.00104 5.3058
 105  77                                      HMPG   FENOX   1264    1264   -0.2565   23.378 0.00524 6.1187
 106  78                                      HMPG   FENOX    834     834   -0.8178   26.279 0.06722 6.3267
 107  79                                      HMPG   FENOX   1448    1448   -0.2986   25.809 0.00319 6.8055
 108  80                                      HMPG   FENOX    201     201   -0.3762   27.992 0.00005 4.9802
 109  74                                      CMPG   FTPHC      3      63    1.6364   21.746 0.66758 1.4703
 110  75                                      CMPG   FTPHC    987     994   -0.2286   17.013 0.02976 4.6048
 111  76                                      CMPG   FTPHC   1869    2133   -0.1913   17.502 0.00602 4.2344
 112  77                                      CMPG   FTPHC   1264    1264   -0.3274   19.083 0.02135 4.8863
 113  78                                      CMPG   FTPHC    834     834   -0.4125   20.501 0.05842 5.0488
 114  79                                      CMPG   FTPHC   1448    1448   -0.3919   20.942 0.00488 5.2497
 115  80                                      CMPG   FTPHC    201     201   -1.3962   22.840 0.07000 3.7030
 116  74                                      CMPG   FTPCO      3      63    2.2141   18.191 1.00000 0.2005
 117  75                                      CMPG   FTPCO    987     994   -0.2401   17.276 0.03990 4.5806
 118  76                                      CMPG   FTPCO   1869    2133   -0.2562   17.780 0.02779 4.1878
 119  77                                      CMPG   FTPCO   1264    1264   -0.4509   19.637 0.05230 4.8084
 120  78                                      CMPG   FTPCO    834     834   -0.6791   21.542 0.13181 4.8480
 121  79                                      CMPG   FTPCO   1448    1448   -0.3629   21.104 0.01923 5.2117
 122  80                                      CMPG   FTPCO    201     201   -0.3717   22.518 0.03521 3.7717
 123  74                                      CMPG   FTPNOX     3      63   -6.1825   32.343 0.95331 0.5511
 124  75                                      CMPG   FTPNOX   973     994   -0.2950   17.262 0.00597 4.6692
 125  76                                      CMPG   FTPNOX  1850    2133   -0.1888   17.694 0.00371 4.2486
 126  77                                      CMPG   FTPNOX  1233    1264   -0.4187   19.376 0.01077 4.9315
 127  78                                      CMPG   FTPNOX   834     834   -0.9788   21.590 0.06577 5.0290
 128  79                                      CMPG   FTPNOX  1448    1448   -0.7179   21.665 0.01649 5.2190
 129  80                                      CMPG   FTPNOX   201     201   -0.3536   22.638 0.00497 3.8303
 130  74                                      CMPG   FEHC       3      63    2.3516   21.992 0.97502 0.4031
 131  75                                      CMPG   FEHC     987     994   -0.2931   16.700 0.00993 4.6516
 132  76                                      CMPG   FEHC    1869    2133   -0.1560   17.245 0.00076 4.2456
 133  77                                      CMPG   FEHC    1264    1264   -0.3147   18.620 0.00457 4.9280
 134  78                                      CMPG   FEHC     834     834   -0.4677   19.947 0.02593 5.1351
 135  79                                      CMPG   FEHC    1447    1448    0.1745   20.474 0.00028 5.2636
 136  80                                      CMPG   FEHC     201     201   -2.1030   22.448 0.04716 3.7482
 137  74                                      CMPG   FECO       3      63    2.3047   20.340 0.93649 0.6427
 138  75                                      CMPG   FECO     963     994   -0.3064   16.882 0.01936 4.6684
 139  76                                      CMPG   FECO    1828    2133   -0.1851   17.314 0.00556 4.2639
 140  77                                      CMPG   FECO    1240    1264   -0.2166   18.641 0.00422 4.9607
 141  78                                      CMPG   FECO     819     834   -0.4078   19.976 0.01887 5.1330
 142  79                                      CMPG   FECO    1325    1448   -0.4188   20.992 0.01215 5.3373
 143  80                                      CMPG   FECO     165     201   -0.5400   22.759 0.04432 3.7555
 144  74                                      CMPG   FENOX      3      63   -4.9750   30.440 0.88217 0.8754
 145  75                                      CMPG   FENOX    987     994   -0.1506   16.948 0.00303 4.6678
 146  76                                      CMPG   FENOX   1869    2133   -0.8366   17.427 0.00119 4.2447
 147  77                                      CMPG   FENOX   1264    1264   -0.1642   18.842 0.00331 4.9311
 148  78                                      CMPG   FENOX    834     834   -0.5806   21.058 0.05370 5.0614
 149  79                                      CMPG   FENOX   1448    1448   -0.1941   20.899 0.00226 5.2566
 150  80                                      CMPG   FENOX    201     201    0.1526   21.970 0.00136 3.8373
```

Two Variable Linear Regression Results Using Data From Vehicle Manufacturers Stratified by Model Year

```
                         CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                         ---------------------------------------------------------
                            FILE:  CERT/MFR            FEB. 27, 1981     PAGE NO.  1

    <------- CATEGORICAL VARIABLES ------->                  ACTUAL   TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)   SIZE     SIZE     COEFF     CONST    R-SQ   STD.ERR   <-------REMARKS -------->
  1  75
  2  76                                     UMPG   FTPHC       3        3    0.5091    17.557 0.16434 9.3332
  3  77                                     UMPG   FTPHC       5        7    5.5321    16.475 0.51724 2.1049
  4  78                                     UMPG   FTPHC     824      966    4.0976    14.846 0.04890 5.4831
  5  79                                     UMPG   FTPHC    1204     1347    2.7378    16.611 0.01463 5.5696
  6  80                                     UMPG   FTPHC    1544     1690    0.1996    18.582 0.00012 4.8273
  7  81                                     UMPG   FTPHC    1470     1567  -10.2590    22.521 0.02502 4.9152
  8  82                                     UMPG   FTPHC    4182     4290  -13.4490    23.263 0.05858 5.6307
  9  75                                     UMPG   FTPHC     554      555  -23.2490    25.998 0.17516 4.2765
 10  76                                     UMPG   FTPCO       3        3    1.2363     8.862 0.97871 1.4897
 11  77                                     UMPG   FTPCO       5        7    0.6078    16.683 0.85145 1.1676
 12  78                                     UMPG   FTPCO     824      966    0.9042    16.521 0.00370 5.6119
 13  79                                     UMPG   FTPCO    1204     1347    0.3553    17.761 0.00049 5.6094
 14  80                                     UMPG   FTPCO    1544     1690   -0.1475    19.634 0.01215 4.7982
 15  81                                     UMPG   FTPCO    1470     1567   -0.5664    21.693 0.02554 4.9138
 16  82                                     UMPG   FTPCO    4182     4290   -0.4487    20.968 0.02513 5.7299
 17  75                                     UMPG   FTPCO     554      555   -0.3299    20.872 0.00013 4.7085
 18  76                                     UMPG   FTPNOX      3        3  -50.2540   156.220 0.82536 4.2667
 19  77                                     UMPG   FTPNOX      5        7    1.5813    16.494 0.18700 2.7315
 20  78                                     UMPG   FTPNOX    824      966   -0.2613    17.461 0.00030 5.6215
 21  79                                     UMPG   FTPNOX   1204     1347    0.6058    17.141 0.00140 5.6069
 22  80                                     UMPG   FTPNOX   1544     1690    1.1992    17.063 0.00972 4.8041
 23  81                                     UMPG   FTPNOX   1470     1567   -0.2877    20.411 0.00082 4.9758
 24  82                                     UMPG   FTPNOX   4182     4290    0.3005    19.644 0.00023 5.8026
 25  75                                     UMPG   FTPNOX    554      555    5.7161    16.636 0.05898 4.5678
 26  76                                     UMPG   FEHC        3        3   31.0530     7.279 0.94910 2.3035
 27  77                                     UMPG   FEHC        4        7   11.5860    17.398 0.79957 1.4189
 28  78                                     UMPG   FEHC      572      966    7.5231    16.130 0.04667 5.7342
 29  79                                     UMPG   FEHC      908     1347    7.0138    17.124 0.02609 5.4889
 30  80                                     UMPG   FEHC     1298     1690    3.6784    18.292 0.01117 4.6793
 31  81                                     UMPG   FEHC     1304     1567    2.5578    20.021 0.00053 4.9724
 32  82                                     UMPG   FEHC      972     4290   -0.5882    22.307 0.00002 6.1982
 33  75                                     UMPG   FEHC       11      555   42.7210    23.831 0.11674 1.6750
 34  76                                     UMPG   FECO        3        3    3.0276    11.021 0.89052 3.3782
 35  77                                     UMPG   FECO        4        7    1.8974    17.826 0.90808 0.9609
 36  78                                     UMPG   FECO      572      966    0.2698    16.763 0.00808 5.8491
 37  79                                     UMPG   FECO      908     1347    0.5154    17.300 0.02750 5.4849
 38  80                                     UMPG   FECO     1298     1690    0.7666    18.622 0.00115 4.7029
 39  81                                     UMPG   FECO     1304     1567   -0.2686    20.155 0.00001 4.9736
 40  82                                     UMPG   FECO      972     4290   -0.5237    22.589 0.00977 6.1679
 41  75                                     UMPG   FECO       11      555    0.3393    24.939 0.00309 1.7795
 42  76                                     UMPG   FENOX       3        3  -13.4960    57.533 0.0406510.0000
 43  77                                     UMPG   FENOX       4        7    1.1218    17.522 0.18099 2.8683
 44  78                                     UMPG   FENOX     572      966   -0.4107    17.836 0.00342 5.8626
 45  79                                     UMPG   FENOX     908     1347    0.6088    16.876 0.00600 5.5452
 46  80                                     UMPG   FENOX    1298     1690    1.7137    16.050 0.05160 4.5826
 47  81                                     UMPG   FENOX    1304     1567    0.7345    19.284 0.00916 4.9508
 48  82                                     UMPG   FENOX     972     4290    2.8403    20.990 0.02200 6.1297
 49  75                                     UMPG   FENOX      11      555    7.4766    23.077 0.23127 1.5626
 50  76                                     HMPG   FTPHC       3        3    0.9115    26.729 0.1697316.3910
                                            HMPG   FTPHC       4        7    4.2570    25.761 0.19994 3.7031
```

Two Variable Linear Regression Results Using Data From Vehicle Manufacturers Stratified by Model Year

```
                                CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                                ---------------------------------------------------------
                                  FILE:  CERT/MFR          FEB. 27, 1981    PAGE NO.  2

         <------- CATEGORICAL VARIABLES ------->                  ACTUAL  TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)  SIZE   SIZE    COEFF    CONST   R-SQ  STD.ERR   <-------REMARKS -------->

  51  77                                     HMPG   FTPHC    576    966   6.9677   20.365 0.06522 7.6069
  52  78                                     HMPG   FTPHC    917   1347   5.1777   22.782 0.03257 6.9085
  53  79                                     HMPG   FTPHC   1300   1690   1.5365   25.616 0.00412 6.3242
  54  80                                     HMPG   FTPHC   1304   1567 -11.8460   31.395 0.02055 6.3953
  55  81                                     HMPG   FTPHC    972   4290 -19.2640   35.417 0.03394 7.7846
  56  82                                     HMPG   FTPHC     11    555  27.9560   34.835 0.22443 3.4589
  57  75                                     HMPG   FTPCO      3      3   2.1806   11.450 0.98075 2.4960
  58  76                                     HMPG   FTPCO      4      7   0.6881   24.856 0.82058 1.7536
  59  77                                     HMPG   FTPCO    576    966   0.1606   23.247 0.00505 7.8479
  60  78                                     HMPG   FTPCO    917   1347   0.7640   24.886 0.00146 7.0187
  61  79                                     HMPG   FTPCO   1300   1690  -0.1737   27.489 0.00902 6.3086
  62  80                                     HMPG   FTPCO   1304   1567  -0.5719   30.227 0.01573 6.4110
  63  81                                     HMPG   FTPCO    972   4290  -1.2997   34.012 0.03574 7.7774
  64  82                                     HMPG   FTPCO     11    555   0.3409   39.000 0.00698 3.9139
  65  75                                     HMPG   FTPNOX     3      3 -88.2490  270.310 0.81984 7.6356
  66  76                                     HMPG   FTPNOX     4      7   0.7534   26.970 0.03382 4.0694
  67  77                                     HMPG   FTPNOX   576    966  -0.2558   24.630 0.00014 7.8672
  68  78                                     HMPG   FTPNOX   917   1347   0.4220   24.775 0.00042 7.0223
  69  79                                     HMPG   FTPNOX  1300   1690   0.9827   25.074 0.00402 6.3245
  70  80                                     HMPG   FTPNOX  1304   1567  -0.5408   29.195 0.00171 6.4565
  71  81                                     HMPG   FTPNOX   972   4290   1.3180   30.589 0.00206 7.9121
  72  82                                     HMPG   FTPNOX    11    555   1.0492   39.114 0.00101 3.9256
  73  75                                     HMPG   FEHC       3      3  54.6200    8.719 0.94687 4.1853
  74  76                                     HMPG   FEHC       6      7 -12.1070   30.974 0.14297 6.8969
  75  77                                     HMPG   FEHC     714    966   7.7147   23.143 0.03915 7.5565
  76  78                                     HMPG   FEHC    1051   1347  10.1670   24.508 0.03307 7.0089
  77  79                                     HMPG   FEHC    1444   1690   5.5643   25.868 0.01374 6.4054
  78  80                                     HMPG   FEHC    1400   1567  -1.8986   28.702 0.00017 6.4205
  79  81                                     HMPG   FEHC    1080   4290   0.5927   31.310 0.00001 7.8609
  80  82                                     HMPG   FEHC      12    555  93.5170   36.742 0.10735 3.6586
  81  75                                     HMPG   FECO       3      3   5.3479   15.236 0.89499 5.8293
  82  76                                     HMPG   FECO       6      7  -1.3187   29.515 0.06231 7.2142
  83  77                                     HMPG   FECO     714    966   0.1623   24.003 0.00305 7.6972
  84  78                                     HMPG   FECO    1051   1347   0.6312   24.894 0.02445 7.0401
  85  79                                     HMPG   FECO    1444   1690  -0.5253   26.569 0.00030 6.4489
  86  80                                     HMPG   FECO    1400   1567  -0.6269   28.635 0.00003 6.4209
  87  81                                     HMPG   FECO    1080   4290  -0.8138   31.825 0.01553 7.7997
  88  82                                     HMPG   FECO      12    555   1.2315   38.928 0.00937 3.8541
  89  75                                     HMPG   FENOX      3      3 -24.6130   99.566 0.0435617.5930
  90  76                                     HMPG   FENOX      6      7   0.1386   27.538 0.00025 7.4491
  91  77                                     HMPG   FENOX    714    966  -0.2045   24.578 0.00048 7.7071
  92  78                                     HMPG   FENOX   1051   1347   1.3593   23.398 0.01777 7.0641
  93  79                                     HMPG   FENOX   1444   1690   2.4570   22.678 0.05596 6.2668
  94  80                                     HMPG   FENOX   1400   1567   0.8011   27.673 0.00665 6.3997
  95  81                                     HMPG   FENOX   1080   4290   3.3975   29.799 0.01948 7.7841
  96  82                                     HMPG   FENOX     12    555   7.2794   37.535 0.04605 3.7821
  97  75                                     CMPG   FTPHC      3      3   0.6413   20.767 0.1665811.6630
  98  76                                     CMPG   FTPHC      4      7   4.5981   20.324 0.33446 2.8206
  99  77                                     CMPG   FTPHC    576    966   5.6828   16.541 0.06240 6.3523
 100  78                                     CMPG   FTPHC    917   1347   3.9208   18.589 0.02490 6.0063
```

Table IV. B-3 (con't)

Two Variable Linear Regression Results Using Data From Vehicle Manufacturers Stratified by Model Year

```
                        CERTIFICATION MICRO DATABASE DATA REGRESSION RUNS SUMMARY
                        ---------------------------------------------------------
                          FILE:  CERT/MFR          FEB. 27, 1981     PAGE NO.  3

      <------- CATEGORICAL VARIABLES ------->                  ACTUAL  TOTAL
CASE TAYR XXXX XXXX XXXX XXXX XXXX XXXX XXXX DEP(Y) IND(X)    SIZE   SIZE     COEFF     CONST    R-SQ  STD.ERR   <-------REMARKS -------->

 101  79                                     CMPG   FTPHC      1300   1690    0.8291   21.079 0.00175 5.2374
 102  80                                     CMPG   FTPHC      1304   1567  -11.4400   25.901 0.02684 5.3866
 103  81                                     CMPG   FTPHC       972   4290  -19.6080   29.684 0.04799 6.6151
 104  82                                     CMPG   FTPHC        11    555   17.3590   27.018 0.24498 2.0283
 105  75                                     CMPG   FTPCO         3      3    1.5477    9.898 0.97957 1.8261
 106  76                                     CMPG   FTPCO         4      7    0.6074   20.047 0.91677 0.9975
 107  77                                     CMPG   FTPCO       576    966    0.1158   18.988 0.00378 6.5479
 108  78                                     CMPG   FTPCO       917   1347    0.5059   20.228 0.00085 6.0800
 109  79                                     CMPG   FTPCO      1300   1690   -0.1251   22.287 0.00684 5.2240
 110  80                                     CMPG   FTPCO      1304   1567   -0.5820   24.857 0.02282 5.3978
 111  81                                     CMPG   FTPCO       972   4290   -1.1774   27.958 0.04003 6.6427
 112  82                                     CMPG   FTPCO        11    555    0.3191   29.389 0.01731 2.3140
 113  75                                     CMPG   FTPNOX        3      3  -62.7980  194.070 0.82307 5.3740
 114  76                                     CMPG   FTPNOX        4      7    1.4783   20.370 0.18673 3.1180
 115  77                                     CMPG   FTPNOX      576    966   -0.7438   19.822 0.00002 6.5602
 116  78                                     CMPG   FTPNOX      917   1347    0.3314   20.082 0.00035 6.0815
 117  79                                     CMPG   FTPNOX     1300   1690    1.0099   20.141 0.00620 5.2257
 118  80                                     CMPG   FTPNOX     1304   1567   -0.4021   23.641 0.00133 5.4568
 119  81                                     CMPG   FTPNOX      972   4290    1.3861   24.743 0.00310 6.7693
 120  82                                     CMPG   FTPNOX       11    555    5.9561   26.806 0.09251 2.2237
 121  75                                     CMPG   FEHC          3      3   38.8300    7.934 0.94776 2.9200
 122  76                                     CMPG   FEHC          4      7   12.3980   20.230 0.76946 1.6601
 123  77                                     CMPG   FEHC        572    966    8.8059   18.528 0.05102 6.4047
 124  78                                     CMPG   FEHC        908   1347    8.1960   19.719 0.02987 5.9831
 125  79                                     CMPG   FEHC       1298   1690    4.3929   20.998 0.01282 5.2119
 126  80                                     CMPG   FEHC       1304   1567    1.2078   23.133 0.00010 5.4601
 127  81                                     CMPG   FEHC        972   4290   -0.3053   25.580 0.0     6.7798
 128  82                                     CMPG   FEHC         11    555   55.0210   28.452 0.11288 2.1986
 129  75                                     CMPG   FECO          3      3    3.7926   12.594 0.89239 4.1910
 130  76                                     CMPG   FECO          4      7    2.1219   20.576 0.95431 0.7390
 131  77                                     CMPG   FECO        572    966    0.3085   19.279 0.00843 6.5469
 132  78                                     CMPG   FECO        908   1347    0.5490   19.981 0.02616 5.9946
 133  79                                     CMPG   FECO       1298   1690    0.3629   21.456 0.00021 5.2451
 134  80                                     CMPG   FECO       1304   1567   -0.3753   23.206 0.00002 5.4604
 135  81                                     CMPG   FECO        972   4290   -0.6275   25.941 0.01172 6.7399
 136  82                                     CMPG   FECO         11    555    1.1443   29.636 0.02045 2.3103
 137  75                                     CMPG   FENOX         3      3  -17.1350   71.501 0.0418512.5060
 138  76                                     CMPG   FENOX         4      7    0.8853   21.101 0.09473 3.2896
 139  77                                     CMPG   FENOX       572    966   -0.3869   20.360 0.00242 6.5667
 140  78                                     CMPG   FENOX       908   1347    0.7642   19.345 0.00792 6.0504
 141  79                                     CMPG   FENOX      1298   1690    1.9813   18.421 0.05550 5.0980
 142  80                                     CMPG   FENOX      1304   1567    0.7800   22.278 0.00857 5.4370
 143  81                                     CMPG   FENOX       972   4290    3.0217   24.197 0.02082 6.7089
 144  82                                     CMPG   FENOX        11    555    6.9892   28.178 0.11781 2.1925
```

highway fuel economy for model year 1978, and composite fuel economy for 1978. These values of r-squared are considered to represent very weak, if any, correlation. The six cases between 1966 and 1971 are consistent and could be further investigated; however, they are for vehicles that are so old that they are no longer of much importance.

R-squared was over 0.100 (.175 was the actual value, see case number 8) once for the 93 cases in the CERT/MFR data base. This case was urban fuel economy as the dependent variable and HC emissions from the FTP as the independent variable for the 1982 model year. This can be found on table IV. B-3 line 8. TAYR corresponds to model year.

Slopes of the Regression Lines

The slopes of the regression lines for all ten cases for which r-squared exceeded 0.100 were all negative.

Even though there was little or no correlation for the regression lines, the slopes of the other regression lines were investigated. The purpose of looking at the slopes was to see if there was any consistency in the signs of the slopes between the 3 data bases. The results are shown in table IV. B-4. There are two things of interest in this table. First, the in-use data base almost always shows negative slopes for the emissions/fuel economy relationships. Malfunctions and maladjustments could possibly explain the negative slopes for HC and CO. This speculation is not based on the results of an analysis, however. An explanation for a negative NOx slope could be the impact of vehicle weight on NOx and fuel economy. This was not confirmed and is also speculative.

Second, there was some consistency between the CERT/EPA and CERT/MFR data bases in terms of the numbers of cases with positive slopes.

Slopes of the Regression Lines for 1981 and 1982 Model Year Vehicles

The 1981 and 1982 model years are of particular interest in this study because 3-way catalyst technology is extensively used in these model years and because 3-way catalyst technology at this point in time appears to be the technology most vehicle manufacturers will use to meet emission requirements in the near future.

It is sufficiently important to repeat that the correlation for the regression lines was very weak or non-existent; however, as can be seen from Table IV. B-5, the slopes of the regression lines for the 1981 model year are surprisingly consistent between the CERT/EPA and CERT/MFR data bases. The slopes for the regressions of 1982 model year data are provided for the few cases for which slopes are available.

Summary

Stratification of the data bases by model year did not provide any real improvements in correlation between emissions and fuel economy. Consistent directional trends for the slopes of the regression lines between the 1981 EPA and manufacturer data bases are evident.

Table IV. B-4

Direction of the Regression Lines for the Three Data Bases Stratified by Model Year

Dependent Variable	Independent Variable	----Data Base----			Number of Cases with + Slope	Total Number of Cases
		CERT/ EPA	EF	CERT/ MFR		
UMPG	FTPHC	x			5	7
			x		0	15
				x	3	6
UMPG	FTPCO	x			3	7
			x		0	15
				x	2	6
UMPG	FTPNOx	x			2	7
			x		1	15
				x	4	6
UMPG	FEHC	x			5	7
			x		1	6
				x	4	5
UMPG	FECO	x			5	7
			x		0	6
				x	3	5
UMPG	FENOx	x			4	7
			x		1	6
				x	4	5
HMPG	FTPHC	x			6	7
			x		0	6
				x	3	5
HMPG	FTPCO	x			3	7
			x		0	6
				x	2	5

Table IV. B-4 (con't)

Direction of the Regression Lines for the Three Data Bases
Stratified by Model Year

Dependent Variable	Independent Variable	----Data Base---- CERT/ EPA	EF	CERT/ MFR	Number of Cases with + Slope	Total Number of Cases
HMPG	FTPNOx	x			1	7
			x		0	6
				x	3	5
HMPG	FEHC	x			6	7
			x		1	6
				x	4	5
HMPG	FECO	x			4	7
			x		0	6
				x	2	5
HMPG	FENOx	x			4	7
			x		0	6
				x	4	5
CMPG	FTPHC	x			5	7
			x		0	6
				x	3	5
CMPG	FTPCO	x			3	7
			x		0	6
				x	2	5
CMPG	FTPNOx	x			1	7
			x		0	6
				x	3	5
CMPG	FEHC	x			5	7
			x		1	6
				x	4	5

Table IV. B-4 (con't)

Direction of the Regression Lines for the Three Data Bases Stratified by Model Year

Dependent Variable	Independent Variable	----Data Base----			Number of Cases with + Slope	Total Number of Cases
		CERT/ EPA	EF	CERT/ MFR		
CMPG	FECO	x			5	7
			x		0	6
				x	3	5
CMPG	FENOx	x			4	7
			x		1	6
				x	4	5

Table IV. B-5

Slopes of the Regression Lines for the 1981 & 1982 Model Year

Dependent Variable	Independent Variable	----Data Base----- CERT/ EPA	EF	CERT/ MFR	----Slope---- for '81 MY	for '82 MY
UMPG	FTPHC	x			- 9.43	
			x		---	
				x	-13.45	-23.25
UMPG	FTPCO	x			- 1.06	
			x		---	
				x	- 0.45	- 0.33
UMPG	FTPNOx	x			2.30	
			x		---	
				x	0.30	5.72
UMPG	FEHC	x			- 8.39	
			x		---	
				x	- 0.59	
UMPG	FECO	x			- 0.86	
			x		---	
				x	- 0.52	
UMPG	FENOx	x			1.89	
			x		---	
				x	2.84	
HMPG	FTPHC	x			-16.18	
			x		---	
				x	-19.26	

Table IV. B-5 (con't)

Slopes of the Regression Lines for the 1981 & 1982 Model Year

Dependent Variable	Independent Variable	----Data Base----- CERT/ EPA	EF	CERT/ MFR	----Slope---- for '81 MY	for '82 MY
HMPG	FTPCO	x			- 1.16	
			x		---	
				x	- 1.30	
HMPG	FTPNOx	x			1.31	
			x		---	
				x	1.32	
HMPG	FEHC	x			- 9.36	
			x		---	
				x	0.59	
HMPG	FECO	x			- 1.03	
			x		---	
				x	- 0.81	
HMPG	FENOx	x			2.19	
			x		---	
				x	3.40	
CMPG	FTPHC	x			-18.05	
			x		---	
				x	-19.61	

Table IV. B-5 (con't)

Slopes of the Regression Lines for the 1981 & 1982 Model Year

Dependent Variable	Independent Variable	----Data Base----- CERT/ EPA	EF	CERT/ MFR	----Slope---- for '81 MY	for '82 MY
CMPG	FTPCO	x			- 1.17	
			x		---	
				x	- 1.18	
CMPG	FTPNOx	x			1.50	
			x		---	
				x	1.39	
CMPG	FEHC	x			-10.57	
			x		---	
				x	- 0.31	
CMPG	FECO	x			- 1.02	
			x		---	
				x	- 0.63	
CMPG	FENOx	x			1.96	
			x		---	
				x	3.02	

IV. C. Stepwise Backward Regression Analysis

Stepwise backward regression analysis was investigated as another approach to see if there was any fuel economy/emissions relationship and if so, what its nature might be.

The process basically involves starting out with a multiple linear regression of MPG as a function of several variables. Then the least important variable as determined by the partial correlation coefficient is dropped and the analysis repeated and the next least important variable dropped, and so on until all of the coefficients are at least 0.1. The process can be started with a large number of variables, the relatively more important variables can be identified and the less important ones discarded for further analysis.

The independent variables that were chosen to start out the process were: N/V ratio, road load horsepower, displacement, weight, rated horsepower, and the six emission values. The dependent variables were the three fuel economy values.

The 1981 CERT/EPA data base was analyzed as a unit, then stratified by manufacturer and transmission type. In contrast to the low values of the correlation coefficient found in cases using the single independent variables discussed earlier, the R-squared values obtained with this approach were substantially higher, typically in the 0.7 to 0.9 range.

We must be aware that this procedure can indicate that a variable is statistically insignificant for any of several reasons which include:

1. The variable may actually be virtually unrelated to fuel economy.
2. The effects of the variable may be partially masked by one or more other variables. For instance, the effects of differences in rated horsepower may be obscured by related changes in com-

pression ratio or displacement. Similarly, variations in N/V ratio could be hidden by axle ratio differences. Appendix 8 includes a discussion of collinearity (i.e., to determine whether the variables are truly independent of one another). Emissions did not appear to be collinear to any other variable.

3. The variable may strongly influence fuel economy; however, that influence may be hidden if the range (i.e. variations) of that variable is very small. For example, the following summary indicates that the least significant variable in determining the urban fuel economy for the 1981 Ford vehicles with manual transmissions was the reciprocal of the test weight (i.e. ETWM1). However, an examination of those test vehicles indicated that there were only two weight ranges. The 3000 to 3125 pound vehicles were offered with 140 and 200 C.I.D. engines, while the 2375 to 2500 pound cars were offered only with a 98 C.I.D. engine. Similarly, ETWM1 is also the least significant variable for Nissan's urban fuel economy, and, again, the maximum variation of the test weight is only 125 pounds within each basic engine. Thus, in both of those cases, a variable (i.e. ETWM1) was indicated to be the least significant when, in actuality, ETWM1 is one of the most important variables in determining urban fuel economy.

In reviewing the results of this analysis, it was determined that the HC and CO highway emissions (FEHC and FECO respectively) were consistently, statistically insignificant variables, and thus could be omitted when we perform a multiple linear regression of each of MPG_u, MPG_h, and MPG_c as a function of the remaining variables. Results of those regressions (except those which were stratified by manufacturer) are in appendix 5. Compression ratio and axle ratio do not appear in these results because they were eliminated on the basis of partial correlation in earlier results.

Summary tables that describe the results of the process are shown below.

Table IV. C-1

SUMMARY OF STEPWISE BACKWARD ANALYSIS FOR URBAN MPG FOR MODEL YEAR 1981

Level of Stratification:	Order in which the variables were dropped:							
All Data	FEHC	FECO	DISP	FTPHC	FENOX			
Conventional Automatic Trans. (CA)	FEHC	FTPCO	FTPHC	FTPNOX	VDHP	FECO	FENOX	
Conventional Manual Trans (CM)	FEHC	FECO	FENOX	DISP	VDHP			
Lockup Auto. Trans. (LA)	FEHC	FTPCO	FECO	RTHP	VDHP	NSVR		
All Chrysler	FENOX	DISP	FTPHC	FTPNOX	FEHC	VDHP	FECO	
All Ford	FTPCO	FTPHC	RTHP	FEHC	FECO			
All GM	FTPCO	FTPHC	FECO	FENOX	VDHP	FTPNOX	NSVR	
All Honda	FEHC	DISP	FTPHC	FTPNOX	ETWM1	VDHP	FECO	FTPCO
All Nissan	ETWM1	FECO	FTPNOX	DISP	FEHC	FTPHC	VDHP	
All Toyota	FEHC	FTPNOX	DISP	RTHP	VDHP	FTPCO	FTPHC	FENOX
Ford/CA	FEHC	RTHP	FTPCO	VDHP	NSVR			
GM/CA	VDHP	FECO	FEHC	NSVR				
Ford/CM	ETWM1	FEHC						
GM/LA	FEHC	RTHP	VDHP	FENOX	FECO	FTPCO	FTPHC	

Table IV. C-2

SUMMARY OF STEPWISE BACKWARD ANALYSIS
FOR HIGHWAY MPG FOR MODEL YEAR 1981

Level of Stratification:	Order in which the variables were dropped:							
All Data	FECO	FEHC	FENOX					
Coventional Automatic Trans. (CA)	FENOX	FEHC	FECO	FTPHC	FTPNOX	FTPCO		
Conventionan Manual Trans (CM)	FENOX	FECO	FEHC					
Lockup Auto. Trans. (LA)	RTHP	FEHC	FTPCO	FECO	FTPHC			
All Chrysler	FTPCO	DISP	FENOX	FTPNOX	FEHC	VDHP	FTPHC	
All Ford	VDHP	FEHC	FTPHC	FTPCO	FECO			
All GM	FECO	FENOX	FTPCO	FEHC	FTPHC			
All Honda	FEHC	ETWM1	FTPNOX	FTPHC	VDHP	FECO	FTPCO	DISP
All Nissan	FEHC	ETWM1	FTPNOX	FTPHC	FECO	DISP	VDHP	
All Toyota	FTPNOX	FEHC	ETWM1	FTPHC				
Ford/CA	FTPHC	FTPCO	FEHC	FECO	FENOX			
GM/CA	NSVR	FTPNOX	FENOX	DISP	FEHC	FECO	FTPCO	
Ford/CM	FEHC	NSVR	DISP	FTPCO	FECO	FENOX		
GM/LA	FEHC	RTHP	FTPCO	FECO	FTPHC			

Table IV. C-3

SUMMARY OF STEPWISE BACKWARD ANALYSIS FOR COMBINED MPG FOR MODEL YEAR 1981

Level of Stratification:	Order in which the variables were dropped:						
All Data	FECO	VDHP	FEHC	FENOX			
Conventional Automatic Trans. (CA)	FEHC	FENOX	FTPHC	FTPCO	FECO	FTPNOX	VDHP
Conventional Manual Trans. (CM)	FECO	FEHC	DISP	VDHP	FENOX		
Lockup Auto. Trans. (LA)	FEHC	FECO	FTPCO	RTHP	VDHP		
All Chrysler	FTPNOX	FENOX	DISP	FTPCO	FEHC	VDHP	FTPHC
All Ford	FTPHC	FTPCO	RTHP	FEHC	FECO		
All GM	FTPCO	FECO	VDHP	FTPHC	FENOX	FTPNOX	
All Honda	FEHC	DISP	ETWM1	FTPNOX	VDHP	FTPHC	
All Nissan	FTPNOX	ETWMI	FECO	DISP	FEHC	FTPHC	VDHP
All Toyota	RTHP	FEHC	FTPNOX	DISP	FTPCO		
Ford/CA	FEHC	FTPHC	VDHP	FTPCO	FECO		
GM/CA	FECO	NSVR	DISP	FENOX	FEHC	FTPNOX	
Ford/CM	FEHC	ETWM1	DISP				
GM/LA	RTHP	FEHC	FECO	FTPCO	FTPHC	FENOX	

IV. D. Residual Analysis

Another analytical approach that was used was a residual analysis based on multiple independent variable regression equations. Briefly, the approach is as follows. Get a regression equation for MPG as a function of several different variables, but not emissions. Compute the residuals by using the equation to predict the actual data. The residuals are the differences between, or the ratios of, the predicted and actual MPG data. Plot and regress these residuals versus emissions to see if any relationships can be seen. In this way most of the fuel economy important variables can be "accounted for" and what is left can be explored to see if there is a residual fuel economy/emissions relationship. The data base utilized here was the CERT/EPA base for the 1981 model year (less Diesels).

The form of the basic multiple regression equation to use was considered next. Rather than specify just one form it was decided to use 3 forms since it was not known if the form of the basic MPG equation would influence the result. We looked for equations that were published and that had reasonable R^2 values (R^2 values of about 0.9 were considered desirable). Three equation forms were selected; they are called the Murrell 1975, Bascunana 1979, and Cheng 1981 equations.

The Murrell 1975 equation came from SAE paper 750958, entitled "Factors Affecting Fuel Economy" by J. Dillard Murrell. The equation contains 5 variables: $(CID \times N/V^{-.8})$, ETW, (RTHP/ETW), (RTHP/CID), and $(CMPR^{0.4} - 1)/(CMPR^{0.4})$.

The Bascunana 1979 equation came from SAE paper 790654 by Jose L. Bascunana, entitled "Derivation and Discussion of a Regression Model for Estimating the Fuel Economy of Automobiles". The 1979 Bascunana equation contains as independent variables: ETW, displacement, and N/V ratio. In contrast to many other equations, the 1979 Bascunana equation involves a product of variables instead of a sum.

The 1981 Cheng equation was developed in this study as an adjunct to the stepwise backward regression analysis study discussed in section IV. C of this report.

The general functional forms of the equations are shown below.

Functional Forms of the MPG Equations

Equation	Form
1975 Murrell*	$MPG = A(CID \times N/V)^{-0.8} + B(ETW)^{-0.67}$ $+ C(RTHP/ETW) + D(RTHP/CID)$ $+ E(CMPR^{0.4} - 1)/CMPR^{0.4} + F$
1979 Bascunana*	$MPG = A[(ETW)^{a} (DISP)^{b} (N/V)^{c}]$
1981 Cheng	$MPG = A(ETW^{-1}) + B(VDHP) + C(DISP) + D(RTHP)$ $+ E(N/V) + F$

For the data bases that they were derived from with the specific constants listed in the references an estimate of the "goodness of fit" is shown below:

R^2 as an Indication of "Goodness of Fit"

Equation	(Type of MPG)	R^2 (original ref)
1975 Murrell	(urban)	0.89
1975 Murrell	(highway)	0.87
1979 Bascunana	(composite)	0.95
1981 Cheng	(urban)	0.90
1981 Cheng	(highway)	0.86
1981 Cheng	(composite)	0.90

---

* Equivalent test weight (ETW) was substituted for inertia weight which was the original variable in the Murrell and Bascunana equations.

For the 1975 Murrell and the 1979 Bascunana equations it was thought inappropriate to use them with their originally determined coefficient values. Instead, the functional forms were kept the same and new coefficients were derived using the MY 1981 data base used in this report. The results are shown in the table below.

Updated Coefficients Using MY 1981 Data Base

1975 Murrell Equation
Coefficients

	Original			Updated		
Coeff.	urban	highway	composite	urban	highway	composite
A	7,909	19,930	N.A.	7,501	29,878	14,989
B	2,824	2,876	N.A.	5,764	3,956	5,602
C	-66.82	5.839	N.A.	-47.36	227.2	36.28
D	0.1224	-2.259	N.A.	-5.025	-16.80	-10.09
E	34.76	39.37	N.A.	16.20	-1.843	-1.700
F	-19.74	-25.24	N.A.	-17.03	-10.69	-8.915
			R^2 =	0.90	0.88	0.91

1979 Bascunana Equation
Coefficients

	Original			Updated		
Coeff.	urban	highway	composite	urban	highway	composite
A	N.A.	N.A.	37,246	141,482	959,401	436,918
a	N.A.	N.A.	-0.4653	-0.8659	-0.7840	-0.8831
b	N.A.	N.A.	-0.4031	-0.1889	-0.3301	-0.2323
c	N.A.	N.A.	-0.4150	-0.2403	-0.6450	-0.4086
			R^2 =	0.90	0.88	0.90

1981 Cheng Equation

Coefficients

	urban	highway	composite
A.	70,077	80,599	77,444
B.	0.2908	-0.4058	0.0458
C.	-0.0044	-0.0301	-0.0084
D.	-0.0291	-0.0271	-0.0366
E.	-0.1047	-0.4356	-0.2187
F.	4.0439	34.546	13.560
R^2 =	0.90	0.86	0.90

Using the updated coefficients, and the original functional forms for all 3 equations, a residual analysis was carried out. Two forms of residuals were studied, actual MPG minus predicted MPG, (called the delta-residual), and actual MPG divided by predicted MPG, (called the ratio-residual). The residuals were scatter plotted against the six emission variables. The initial stratification was based on all the 1981 data implying 108 scatter plots (3 fuel economy dependent variables x 3 equations x 2 residuals per dependent variable x 6 variables). The plots did not suggest any linear or other relationship between the residuals of fuel economy and emissions.

Upon examining the results of the 108 plots, linear regressions were performed for all the plots, and all the r^2 terms were so small as to be insignificant. The regression results are presented in appendix 6. The largest of the r^2 values, 0.042, was for the ratio-residual of combined fuel economy (MPG_c) regressed against urban NOx (FTPNOX). This result implies that only 4.2% of the variability in the percentage by which the actual MPG_c differs from the MPG_c predicted by the 1979 Bascunana equation could be explained as a linear function of the urban NOx; the remaining 95.8% was not related to FTPNOX. Since most (58 out of 108) of the r^2 values were less than 1% (the average r^2 was only 1.1%), only a small proportion of the total variation of any of the 18 residuals can be explained by a linear function of the 6 emission variables.

Another way to consider this type of information is to forget residual analysis and use improvement in R^2 and standard error as an indicators that emissions do or do not relate to fuel economy. The following data illustrate multiple regressions using the Cheng equation with and without the six emissions as independent variables.

Dependent	--Without Emissions--		--With Emissions--		-Change in:--	
Variable	R^2	Standard Error(SE)	R^2	Standard Error(SE)	R^2	SE
UMPG	.898	1.760	.903	1.819	+.005	+.059
HMPG	.864	2.776	.867	2.879	+.003	+.103
CMPG	.897	2.064	.902	2.026	+.005	-.038

These data indicate that inclusion or exclusion of the urban and highway emissions in the Cheng equation makes virtually no difference. It can be concluded that for the 1981 EPA certification data base, exhaust emissions have essentially no identifiable relationship to fuel economy after accounting for variability in fuel economy due to vehicle design parameters. This conclusion is restricted to the 1981 EPA certification data base due to somewhat limited ranges for emissions (these are expanded in section IV. H) and collinearity of variables in the Cheng equation (see appendix 8).

Section IV. E. Subconfiguration - Matched Data Analysis

Another analysis method was to restrict the study to the 1981 CERT/EPA data base and then stratify by the following ten (10) parameters:

1. Manufacturer
2. Engine Family
3. Displacement
4. Vehicle I.D.
5. Transmission
6. ETW
7. Dynamometer Horsepower
8. Axle Ratio
9. N/V
10. Compression Ratio

The purpose of such a stratification was to identify, as closely as possible, the effect of engine calibration on emissions and fuel economy for each vehicle that was tested at the EPA laboratory in more than one configuration. Also this tended to eliminate test variability which was due to either differences among the test vehicles or to differences among the vehicle testing laboratories. The disadvantage of such a stratification was that only 27 such vehicles were identified, each of which was tested at EPA in at least two (2) versions.

In examining the results the following relationships between the urban fuel economy (MPG_u) and the regulated emissions were seen.

1. For FTPHC:

    a. MPG_u increased as FTPHC decreased, in 18 of the 27 cases,

b. MPG_u decreased as FTPHC decreased, in 8 of the 27 cases, and

c. MPG_u remained unchanged in one (1) of the 27 cases.

2. For FTPCO:

a. MPG_u increased as FTPCO decreased, in 23 of the 27 cases, and

b. MPG_u decreased as FTPCO decreased, in four (4) of the 27 cases.

3. For FTPNOX:

a. MPG_u increased as FTPNOX decreased, in nine (9) if the 27 cases, and

b. MPG_u decreased as FTPNOX decreased, in 18 of the 27 cases.

The following chart illustrates the seven (7) combinations of outcomes that we found in examining those 27 groups of data.

As MPG_u increases, the level of the corresponding emissions were observed to:

	Number of Occurrences	FTPHC	FTPCO	FTPNOX
Outcome 1	10	Decreases	Decreases	Increases
Outcome 2	7	Decreases	Decreases	Decreases
Outcome 3	5	Increases	Decreases	Increases
Outcome 4	2	Increases	Increases	Increases
Outcome 5	1	Increases	Increases	Decreases
Outcome 6	1	Decreases	Increases	Increases
Outcome 7	1	Unchanged	Decreases	Decreases

Thus, from this rather limited set of data (shown in table IV. E-1), we can infer that decreasing the level of the FTPHC or FTPCO emissions is not usually detrimental to MPG_u. But decreasing the level of FTPNOX emissions usually accompanies a decrease in MPG_u.

Table IV. E-1

MFR	VID	VER	VOHP	DISP	CYL	CRB	BBL	FI2	COMP. RATIO	AXLE RATIO	N/V	TRN	EMISSION CONTROL SYSTEM	TEST#	ETW	UMPG	ETPHC	ETPCO	ETPNOX
FORD	1E2-1.6-F-441	1	6.4	98.0	4	1	2	N	8.8	3.59	43.0	M4	EGR,PMP,OXD,RED	805348	2375	27.9	0.260	2.220	0.520
FORD	1E2-1.6-F-441	3	6.4	98.0	4	1	2	N	8.8	3.59	43.0	M4	EGR,PMP,OXD,RED	806864	2375	27.3	0.294	2.750	0.570
FORD	1K2-2.3-C-285	3	10.4	140.0	4	1	2	N	9.0	3.08	43.0	M4	EGR,PMP,OXD,3CL	806678	3125	21.3	0.381	3.220	0.510
FORD	1K2-2.3-C-285	3	10.4	140.0	4	1	2	N	9.0	3.08	43.0	M4	EGR,PMP,OXD,3CL	806574	3125	21.4	0.426	3.970	0.550
FORD	1K2-2.3-C-285	4	10.4	140.0	4	1	2	N	9.0	3.08	43.0	M4	EGR,PMP,OXD,3CL	807680	3125	21.4	0.286	2.620	0.470
FORD	1K2-2.3-C-285	5	10.4	140.0	4	1	2	N	9.0	3.08	43.0	M4	EGR,PMP,OXD,3CL	807366	3125	22.1	0.351	2.570	0.760
FORD	1K2-2.3-C-285	5	10.4	140.0	4	1	2	N	9.0	3.08	43.0	M4	EGR,PMP,OXD,3CL	807453	3125	22.2	0.269	1.750	0.650
FORD	1K2-2.3-G-286	0	10.4	140.0	4	1	2	N	9.0	3.08	44.0	M4	EGR,PMP,OXD,3CL	805808	3125	22.9	0.288	3.600	0.850
FORD	1K2-2.3-G-286	0	10.4	140.0	4	1	2	N	9.0	3.08	44.0	M4	EGR,PMP,OXD,3CL	805901	3125	23.0	0.372	3.930	0.900
FORD	1K2-2.3-G-286	1	10.4	140.0	4	1	2	N	9.0	3.08	44.0	M4	EGR,PMP,OXD,3CL	806116	3125	23.3	0.326	2.180	1.580
FORD	1K2-2.3-G-286	1	10.4	140.0	4	1	2	N	9.0	3.08	44.0	M4	EGR,PMP,OXD,3CL	806183	3125	23.2	0.362	2.570	1.170
FORD	1K2-2.3-G-286	1	10.4	140.0	4	1	2	N	9.0	3.08	44.0	M4	EGR,PMP,OXD,3CL	806375	3125	23.0	0.365	2.850	0.900
FORD	1Z2-2.3-C-290	0	8.9	140.0	4	1	2	N	9.0	3.45	37.0	M5	EGR,PMP,OXD	805831	3125	21.2	0.321	2.190	0.770
FORD	1Z2-2.3-C-290	1	8.9	140.0	4	1	2	N	9.0	3.45	37.0	M5	EGR,PMP,OXD	806191	3125	20.0	0.376	2.510	0.550
FORD	1Z2-2.3-C-290	1	8.9	140.0	4	1	2	N	9.0	3.45	37.0	M5	EGR,PMP,OXD	806305	3125	20.6	0.352	2.310	0.600
FORD	1S1-4.2-F-345	1	11.0	255.0	8	1	2	N	8.2	3.08	28.0	L4	EGR,PMP,OXD,RED	805884	3750	18.1	0.248	1.040	0.790
FORD	1S1-4.2-F-345	2	11.0	255.0	8	1	2	N	8.2	3.08	28.0	L4	EGR,PMP,OXD,RED	806720	3750	17.0	0.294	1.400	0.820
FORD	1A1-5.8W-G-259	0	12.6	351.0	8	1	2	N	8.3	2.73	23.0	L4	EGR,PMP,OXD,3CL	805919	4500	13.8	0.207	1.060	1.050
FORD	1A1-5.8W-G-259	1	12.6	351.0	8	1	2	N	8.3	2.73	23.0	L4	EGR,PMP,OXD,3CL	806204	4500	13.9	0.272	1.740	0.750
FORD	1A1-5.8W-G-259	1	12.6	351.0	8	1	2	N	8.3	2.73	23.0	L4	EGR,PMP,OXD,3CL	806299	4500	13.6	0.293	3.260	0.660
FORD	1A1-5.8W-G-259	2	12.6	351.0	8	1	2	N	8.3	2.73	23.0	L4	EGR,PMP,OXD,3CL	806572	4500	13.7	0.251	1.540	0.820
GM	C0M079	0	10.6	231.0	6	1	2	N	8.6	2.41	32.8	L3	EGR,PMP,OXD,3CL	802370	3625	18.4	0.225	2.200	0.640
GM	C0M079	1	10.6	231.0	6	1	2	N	8.6	2.41	32.8	L3	EGR,PMP,OXD,3CL	806386	3625	18.4	0.183	1.600	0.650
GM	P0288	0	12.2	265.0	8	1	2	N	8.3	2.41	32.8	L3	EGR,PMP,OXD,3CL	803041	4000	17.1	0.223	1.040	0.790
GM	P0288	1	12.2	265.0	8	1	2	N	8.3	2.41	32.8	L3	EGR,PMP,OXD,3CL	804167	4000	16.7	0.220	1.690	0.530
GM	C09023	1	10.3	268.5	8	1	2	N	8.3	2.41	30.2	L3	EGR,PMP,OXD,3CL	803482	4000	17.6	0.156	1.350	0.680
GM	C08023	1	10.3	268.5	8	1	2	N	8.3	2.41	30.2	L3	EGR,PMP,OXD,3CL	803569	4000	17.3	0.233	2.340	0.700
GM	C08023	2	10.3	268.5	8	1	2	N	8.3	2.41	30.2	L3	EGR,PMP,OXD,3CL	805865	4000	17.6	0.177	1.650	0.610
GM	CA7403-A	0	14.5	367.0	8	0	0	Y	8.2	3.08	38.2	A3	EGR,PMP,OXD,3CL	806869	5250	11.2	0.169	1.020	0.760
GM	CA7403-A	2	14.5	367.0	8	0	0	Y	8.2	3.08	38.2	A3	EGR,PMP,OXD,3CL	807294	5250	10.4	0.217	1.940	0.810
JRT	XJ52/16	0	11.3	258.0	6	0	0	Y	8.1	3.07	40.6	A3	3CL	806388	4250	15.4	0.221	2.320	0.260
JRT	XJ52/16	1	11.3	258.0	6	0	0	Y	8.1	3.07	40.6	A3	3CL	806429	4250	15.6	0.227	2.620	0.530
JRT	XJ52/15	0	11.3	258.0	6	0	0	Y	8.1	3.07	40.6	A3	PMP,3CL	806478	4250	14.5	0.235	2.880	0.230
JRT	XJ52/15	0	11.3	258.0	6	0	0	Y	8.1	3.07	40.6	A3	PMP,3CL	806524	4250	14.6	0.225	2.690	0.190
JRT	XJ52/15	0	11.3	258.0	6	0	0	Y	8.1	3.07	40.6	A3	PMP,3CL	806664	4250	14.7	0.068	0.580	0.750
JRT	XJ52/15	1	11.3	258.0	6	0	0	Y	8.1	3.07	40.6	A3	PMP,3CL	806719	4250	15.4	0.084	0.750	1.000
SAAB	668	1	9.2	121.1	4	0	0	Y	7.2	3.89	43.7	M5	EGR,3CL	806158	3125	18.2	0.303	2.260	0.170
SAAB	668	2	9.2	121.1	4	0	0	Y	7.2	3.89	43.7	M5	EGR,3CL	806322	3125	18.8	0.208	2.160	0.230
TOYOTA	81-FE-4	0	7.8	88.6	4	1	2	N	9.0	3.31	51.7	M4	EGR,PLS,OXD	803519	2250	36.5	0.147	0.850	0.740
TOYOTA	81-FE-4	1	7.8	88.6	4	1	2	N	9.0	3.31	51.7	M4	EGR,PLS,OXD	806816	2250	34.9	0.160	1.030	0.680
TOYOTA	81-FE-17	2	10.2	108.0	4	1	2	N	9.0	3.73	55.6	A3	EGR,PMP,3CL,OTR	806817	2625	25.5	0.069	0.680	0.460
TOYOTA	81-FE-17	3	10.2	108.0	4	1	2	N	9.0	3.73	55.6	A3	EGR,PMP,3CL,OTR	806820	2625	26.8	0.072	0.670	0.470
TOYOTA	81-FE-13	0	11.5	144.4	4	1	2	N	9.0	3.58	34.5	A4	EGR,PMP,3WY,OTR	803645	3000	23.0	0.100	1.300	0.640
TOYOTA	81-FE-13	1	11.5	144.4	4	1	2	N	9.0	3.58	34.5	A4	EGR,PMP,3WY,OTR	805786	3000	22.9	0.100	1.370	0.660

Section IV. F. Special Engine Over Time Trends

In an attempt to examine the question of fuel economy versus emission standards, a review of five major engine displacement groupings was undertaken to see the effects on fuel economy with increasingly stringent Federal emission standards. The model years selected (1979, 1980, and 1981) were chosen because these three years have three different sets of emission standards and represent the most recent automotive and emission control technology. The engine groupings chosen represented high production volume designs that in turn represent the trend for future automotive applications.

The objective was to match up, within the limits of the test data which were used to generate the EPA fuel economy label values,* similar vehicles of differing model year, and see how fuel economy varied with differing emission levels. The matching was to incorporate as many possible vehicle and powerplant design parameters as the data base was capable of providing, in order to eliminate to the maximum extent possible the influence of vehicle and power plant design differences. This was not always possible, due to the variability of product offerings from model year to model year. In every case, however, the closest possible matching was arrived at utilizing the EPA Test Car List data base. The power plant and vehicle design parameters considered for matching are noted below:

Powerplant Design Parameters

Swept Volume (displacement)
Induction System (carburetor design i.e., 2 barrel, 4 barrel, etc.)
Compression Ratio
Manufacturer's Rated Power Output
Emission Control System

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* EPA Test Car List, Second Edition 1979, Second Edition 1980, and Second Edition 1981.

Vehicle Design Parameters

Weight
Transmission Type
Axle Ratio
N/V Ratio
Road Load Horsepower (RLHP)

By "walking through" the noted model years and matching the above noted parameters to the maximum extent possible within a given engine displacement grouping, data were compiled to address the fuel economy versus emissions question. The following five tables are the results of this "walk through" procedure. After carefully reviewing the tables and their associated graphs, it becomes apparent that no readily discernible trend is evident with respect to fuel economy versus emissions since there are instances when fuel economy increases accompany both increases and decreases in emissions. These data are all plotted and included in this document as appendix 7.

Looking at the data for various engine families, some tentative conclusions can be arrived at.

Ford 2.3 L Powerplant (Table IV. F-1)

For automatic transmission equipped vehicles, the slight increase in fuel economy is of the magnitude expected with a decrease in RLHP with progressing model years. For manual transmission vehicles, an increase in fuel economy was noted with decreasing emissions, which coincided with a major change in emission control technology.

Chrysler 1.7 L Powerplant (Table IV. F-2)

For automatic transmission equipped vehicles, there was no consistent change in fuel economy, either city or highway, as emissions decreased. As the emissions decreased each year from 1979 to 1981, the fuel economy dropped in 1980 and then increased in 1981.

Table IV. F-1

Ford 2.3 Liter Powerplant

MY 79 - 140 C.I.D. 2 bbl carb.,
9.0 C.R. 92 BHP Manf. Rating

Automatic Transmission Vehicles - EGR/OXD

Manual Transmission Vehicles - EGR/PMP/OXD

MY 80 - 140 C.I.D., 2 bbl carb., 9.0 C.R.
92 BHP Manf. Rating
EGR/PMP/OXD

MY 80 (Calif) - 140 C.I.D. 2 bbl carb.,
9.0 C.R. 92 BHP Manf. Rating,
EGR/PMP/OXD/3CL

MY 81 - 140 C.I.D., 2 bbl carb., 9.0 C.R.
92 BHP Manf. Rating, EGR/PMP/OXD/3CL

					Emissions						F.E.		
					City			Highway					
MY	Wt	Trans	Axle/N/V	RLHP	HC	CO	NOx	HC	CO	NOx	City	Hwy	Comb
79	3000	A3-1	3.08/43.0	10.2	.41	7.80	1.48	.05	.50	2.18	20.5	29.3	23.7
80	3000	A3-1	3.08/43.0	9.7	.178	3.09	1.33	.033	.10	2.26	20.9	29.1	23.9
81	3000	A3-1	3.08/43.0	8.5	.101	1.96	.41	.014	.01	.18	21.5	30.5	24.8
79	3000	M4-1	3.08/43.0	10.2	.91	4.70	1.46	.16	.20	2.15	20.8	32.3	24.8
80	3125	M4-1	3.08/43.0	10.2	.22	1.76	1.40	.065	.02	2.45	21.3	33.2	25.4
81	3125	M4-1	3.08/43.0	10.4	.267	1.75	.46	.045	.14	.18	22.6	31.7	26.0
Calif													
80	3000	A3-1	3.08/43.0	8.0	.282	3.58	.44	.034	.04	.40	21.1	31.5	24.8
80	3125	M4-1	3.08/43.0	10.2	.296	3.96	.63	.026	.27	.49	20.0	31.1	23.8

Table IV. F-2

Chrysler 1.7 Liter Powerplant

MY 79 - 105 C.I.D., 2 bbl carb.,
8.2 C.R., 75 BHP Manf. Rating,
EGR/PLS/OXD

MY 80 - 105 C.I.D., 2 bbl carb., 8.2 C.R.,
65 BHP Manf. Rating, EGR/PMP/OXD

MY 80 (Calif) - 105 C.I.D., 2 bbl, 8.2 C.R.,
65 BHP Manf. Rating, EGR/PMP/OXD/3CL

MY 81 - 105 C.I.D., 2 bbl. carb., 8.2 C.R.,
65 BHP Manf. Rating, EGR/PMP/OXD/3CL

					Emissions						F.E.		
					City			Highway					
MY	Wt	Trans	Axle/N/V	RLHP	HC	CO	NOx	HC	CO	NOx	City	Hwy	Comb
79	2500	A3-1	3.48/53.4	6.6	.26	7.2	1.36	.04	.90	2.84	24.0	32.7	27.3
80	2500	A3-1	3.48/53.4	7.1	.178	3.32	1.21	.011	.11	1.89	23.8	31.2	26.6
81	2500	A3-1	3.48/53.3	6.9	.147	2.07	.79	.015	.07	.69	24.5	34.2	28.1
80	2625	M4-1	3.37/50.2	7.4	.180	2.39	1.00	.014	.12	1.13	23.3	33.3	26.9
81	2625	M4-1	3.37/50.4	6.9	.125	1.28	.63	.018	.01	.54	26.4	39.4	31.0
79	2500	M4-2	3.37/49.3	7.4	.36	11.70	1.60	.04	.70	4.41	26.4	37.8	30.6
81	2500	M4-2	3.13/47.9	7.4	.144	1.65	.67	.015	.04	.49	26.9	41.2	31.9
Calif													
80	2500	A3-1	3.48/53.4	7.1	.168	1.86	.86	.010	.06	.68	23.0	31.9	26.3
80	2500	M4-1	3.37/50.2	6.7	.204	3.38	.61	.020	.10	.70	24.4	38.0	29.1

For manual transmission vehicles, fuel economy increased as emissions decreased. Thus both the automatic and manual transmission equipped vehicles exhibited fuel economy increases which coincided with the incorporation of more advanced emission control technology.

General Motors 1.6 L Powerplant (Table IV. F-3)

There were two versions of the GM 1.6 L engine reviewed, the base or standard engine and an optional H.O. (high output) version. Fuel economy results with respect to emissions differed markedly between these two versions of the engine. For the standard engine with automatic transmission, there was a significant increase in fuel economy with decreasing emissions. For the manual transmission equipped version of the standard engine there was a decrease in fuel economy between 1979 and 1980, only partly attributable to increased road load horsepower. Again, there was an increase in fuel economy coinciding with the utilization of an advanced emission control system. For the H.O. version of the engine, a different set of results emerged. Both the automatic transmission and manual transmission versions of this engine exhibited noticeable declines in fuel economy with decreasing emission levels. It is not obvious from the data available why the fuel economy versus emissions relation is so different for the standard and high output versions of this powerplant.

General Motors 2.5 L Powerplant (Table IV. F-4)

For both vehicles equipped with either automatic or manual transmissions, the significant drops in fuel economy appear to be associated with the engine being used to power front-wheel drive (FWD) vehicles instead of rear-wheel drive (RWD) vehicles. This drop in tested fuel economy might not be indicative of a real difference in the in-use fuel economies. (There is evidence to the effect that rear-drive vehicles have larger offsets of actual in-use fuel economy versus dynamometer fuel economy test results than do front-drive vehicles.*) The slight drop in fuel economy for the RWD

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* - Neil South, "1978 to 1980 Ford On-Road Fuel Economy," SAE Paper 810383, February 1981.
- Schneider, et al., "In-Use Fuel Economy of 1980 Passenger Cars," SAE Paper 810384, February 1981.
- Section III. D of this report.

Table IV. F-3

General Motors 1.6 Liter Powerplant

MY 79 - 98 C.I.D., 2 bbl carb., 8.6 C.R.,
70 BHP Manf. Rating, EGR/OXD
74 BHP H.O. Manf. Rating, EGR/OXD

MY 80 - 98 C.I.D., 2 bbl carb., 8.6 C.R.,
70 BHP Manf. Rating, EGR/PLS/OXD
74 BHP H.O. Manf. Rating, EGR/PLS/OXD

MY 80 (Calif) - 98 C.I.D., 2 bbl carb., 8.6 C.R.,
70 BHP Manf. Rating, EGR/PLS/3CL

MY 81 - 98 C.I.D., 2 bbl carb., 8.6 C.R.,
70 BHP Manf. Rating, EGR/PLS/3CL

					Emissions						F.E.		
					City			Highway					
MY	Wt	Trans	Axle/N/V	RLHP	HC	CO	NOx	HC	CO	NOx	City	Hwy	Comb
79 Std	2500	A3-1	3.70/56.5	9.2	.43	9.00	1.47	.03	1.57	.78	23.3	25.8	24.3
80 Std	2500	A3-1	3.70/56.5	9.8	.188	3.01	1.39	.026	.38	1.25	26.1	31.0	28.1
81 Std	2500	A3-1	3.70/56.5	9.8	.178	3.68	.28	.106	3.24	.04	25.8	32.3	28.4
79 HO	2500	A3-1	3.70/56.5	9.2	.89	11.80	1.11	.07	.90	1.76	26.4	34.7	29.8
80 HO	2500	A3-1	3.70/56.5	9.8	.206	2.96	1.41	.041	.03	1.47	23.0	28.3	25.1
79 Std	2500	M4-1	3.70/56.5	9.2	.55	8.25	1.46	.05	.55	1.85	28.3	39.1	32.3
80 Std	2500	M4-1	3.70/56.5	9.8	.163	4.47	1.05	.026	.46	1.41	24.7	33.2	27.9
81 Std	2500	M4-1	3.70/56.5	9.8	.176	3.06	.47	.021	.67	.15	27.4	36.3	30.8
79 HO	2250	M4-1	3.70/56.5	9.2	.67	8.30	.71	.06	.70	1.28	28.4	38.8	32.3
80 HO	2375	M4-1	3.70/56.7	8.9	.234	3.70	1.31	.041	.23	1.66	26.3	36.4	30.1
Calif													
80	2500	A3-1	3.70/56.7	8.9	.123	1.99	.40	.020	.55	.03	24.7	30.6	27.0
80	2375	M4-1	3.70/56.5	8.9	.171	5.00	.12	.040	.63	.04	26.0	37.2	30.1

Table IV. F-4

GM Corp. 2.5 Liter L-4 Powerplant

MY 79 - 151 C.I.D., 2 bbl carb., 8.1 C.R.,
90 BHP Manf. Rating, EGR/OXD

MY 80 - 151 C.I.D., 2 bbl carb., 8.2 C.R.,
90 BHP Manf. Rating, EGR/OXD/PLS

MY 80 (Calif)-151 C.I.D., 2 bbl carb., 8.1 C.R.,
90 BHP Manf. Rating, EGR/3CL

MY 81 - 151 C.I.D., 2 bbl carb., 8.1 C.R.,
90 BHP Manf. Rating, EGR/PMP/OXD/3CL

					Emissions						F.E.		
					City			Highway					
MY	Wt	Trans	Axle/N/V	RLHP	HC	CO	NOx	HC	CO	NOx	City	Hwy	Comb
79	3000	A3-1/RWD	2.73/39.9	8.3	.39	7.20	1.54	.06	.60	1.63	24.3	32.5	27.4
80	3125	A3-1/RWD	2.73/39.9	8.2	.163	2.96	1.37	.027	.34	1.23	24.2	31.6	27.1
80	3000	A3-1/FWD	2.84/35.7	7.3	.223	2.17	1.21	.040	.40	1.16	21.1	31.9	24.9
81	3000	A3-1/FWD	2.53/35.7	7.3	.113	1.15	.66	.035	.46	.31	22.1	32.5	25.8
81	3000	A3-1/FWD	2.53/35.7	7.3	.135	1.77	.52	.035	.80	.29	21.8	31.5	25.3
79	3000	M4-1/RWD	2.73/39.9	8.3	.46	6.50	.99	.05	1.10	1.08	23.7	37.4	28.4
80	3000	M4-2/FWD	3.34/38.6	7.3	.192	2.84	1.55	.023	.19	1.45	22.9	34.1	26.9
80	3000	M4-2/FWD	3.34/38.6	7.3	.254	3.89	1.42	.027	.19	1.35	22.1	34.6	26.4
81	3000	M4-2/FWD	3.32/38.0	7.3	.175	1.01	.68	.027	.18	.15	21.6	35.0	26.1
Calif													
80	3000	A3-1/FWD	2.84/35.7	7.3	.300	4.49	.33	.025	.32	.33	22.3	33.8	26.3
80	3000	M4-2/FWD	3.34/38.2	7.3	.328	3.33	.94	.019	.12	.75	23.8	35.9	28.1

vehicles equipped with automatic transmissions (from 1979 to 1980) is of the magnitude expected with a 125 pound increase in test weight. There is a slight drop in fuel economy for the FWD vehicles equipped with manual transmissions from 1980 to 1981. For the automatic transmission equipped FWD vehicles, the increase (from 1980 to 1981) coincides with the use of more advanced emission control technology on the 1981 models. However, since the cylinder heads also underwent substantial design changes during those three years, it is known that other factors are probably influencing the fuel economy, too.

General Motors 3.8 L Powerplant (Table IV. F-5)

For automatic transmission equipped vehicles, the increase in fuel economy appears to be attributable primarily to the usage of a lock-up torque converter on MY 81 vehicles. For manual transmission vehicles the slight decrease in fuel economy between 1979 and 1980 appears to be partly attributable to an increase in test weight and rear axle ratio. Again, an increase in fuel economy coinciding with the adoption of an advanced control system can be seen.

Summary

After reviewing the comparisons, the only apparent trend (with the exception of a 2.1% drop in fuel economy associated with the 2.5 L vehicles equipped with manual transmissions) is an increase in fuel economy from the 1980 to the 1981 model year, which coincides with the replacement of oxidizing catalyst systems with more sophisticated 3-way catalyst systems. The average increase in combined fuel economy (MPG_c) that accompanied replacing an open-loop oxidation catalyst system with a closed-loop 3-way catalyst system was 5.3%. However, since this "trend" includes increases in fuel economy as small as 1.1%, we tested this trend by comparing 1980 Federal test vehicles with similar 1980 California vehicles. The 1980 Federal vehicles were all equipped with oxidation catalyst systems while the California vehicles were all equipped with 3-way catalyst systems.

Table IV. F-5

GM Corp. 3.8 Liter V-6 Powerplant

MY 79 - 231 C.I.D., 2 bbl carb., 8.0 C.R.,
115 BHP Manf. Rating, EGR/OXD/OTR

MY 80 - 231 C.I.D., 2 bbl carb., 8.0 C.R.,
115 BHP Manf. Rating, EGR/PMP/OXD

MY 80 (Calif) - 231 C.I.D. 2 bbl carb., 8.0 C.R.,
115 BHP Manf. Rating, EGR/PMP/3CL

MY 81 - 231 C.I.D., 2 bbl carb., 8.0 C.R.,
110 BHP Manf. Rating, EGR/PMP/3CL

					Emissions							F.E.	
						City			Highway				
MY	Wt	Trans	Axle/N/V	RLHP	HC	CO	NOx	HC	CO	NOx	City	Hwy	Comb
79	3500	A3-1	2.41/32.7	12.2	.62	5.20	1.19	.07	.60	1.56	19.5	25.0	21.6
80	3500	A3-1	2.41/32.7	10.5	.295	4.20	1.32	.056	.18	1.17	19.6	26.8	22.3
81	3750	L3-1	2.41/32.8	10.9	.221	2.70	.50	.029	.31	.17	20.7	30.1	24.1
79	3500	M3-1	2.93/39.8	12.2	.62	7.40	1.44	.04	.20	1.54	17.5	26.0	20.5
80	3625	M3-1	3.08/41.8	11.3	.312	2.96	.79	.039	.17	.80	16.2	23.7	18.9
81	3625	M3-1	3.08/42.9	11.3	.229	3.23	.74	.017	.03	.64	16.8	26.8	20.2
Calif.													
80	3625	A3-1	2.41/32.7	11.2	.205	2.62	.55	.050	.43	.08	19.7	26.8	22.4
80	3375	M4-1	2.93/43.3	9.0	.244	4.97	.50	.029	.38	.59	15.8	26.3	19.3
Federal													
80	3375	M4-1	2.93/42.8	9.0	.344	4.63	1.23	.040	.50	1.26	14.9	24.9	18.2

The ten (10) comparisons between similar 1980 MY Federal vehicles and 1980 MY California vehicles (detailed in the previous 5 tables) indicate an increase in fuel economy with the addition of a 3-way, closed-loop system occurred in 7 out of the 10 cases. The average increase in fuel economy, for the 10 cases, which accompanied the utilization of a closed-loop 3-way catalyst system was 2.6%.

Thus, there appears to be a trend indicating a slight increase in fuel economy when an open-loop oxidizing catalyst system is replaced with a closed-loop 3-way catalyst system. However, since the amount of data is limited and the absolute value of the fuel economy improvement is not large relative to test variability, all that can be said is that, based on this engines over time study, there appears to be no identifiable fuel economy penalty which can be attributed to changes in the Federal emission standard between 1979 and 1981.

IV. G. Sensitivity Coefficient Study

In yet another way to investigate fuel economy/emissions relationships a sensitivity analysis was undertaken. A sensitivity coefficient can be thought of as sort of a normalized derivative, and is usually expressed as percent change in the dependent variable per percent change in independent variable. Suppose there are two points a and b, with FE_a, FE_b, and if for this example the pollutant is HC, then we have HC_a and HC_b.

$$\text{Let } \overline{FE} = (FE_a + FE_b) \div 2, \ \overline{HC} = (HC_a + HC_b) \div 2,$$

$$\text{and } \Delta FE = FE_b - FE_a, \ \Delta HC = HC_b - HC_a.$$

Then the sensitivity, call it SFEHC, is equal to $\Delta FE/\overline{FE} \div \Delta HC/\overline{HC}$. Besides giving an indication of the magnitude of the effect, the algebraic sign of the sensitivity coefficient can contain useful information. Since the quantities $\overline{FE}$ and $\overline{\text{emissions}}$ are positive, the sign of the sensitivity coefficient is determined by the signs of the deltas. Four cases are possible, and they are shown below:

	ΔEmissions	
ΔFE	ΔEmissions > 0	ΔEmissions < 0
ΔFE > 0	S > 0	S < 0
ΔFE < 0	S < 0	S > 0

Two cases are possible for the sensitivity coefficient. Either it is positive or negative. If it is positive then whenever fuel economy goes up, so do emissions, and vice versa. If the sensitivity coefficient is negative, then then when fuel economy goes up, emissions go down, and vice versa.

What was done was to search the CERT/EPA data base (for 1975 to 1982 model years) for multiple tests of the same vehicle. From the multiple tests the maximum number of sensitivity coefficients were determined.

The results are shown below:

Variables for		No. of Tests	Sensitivity Coefficient			
MPG	Pollutant	N	Mean	Max	Min	Sigma
MPG Urban	HC Urban	1026	+0.001	31.8	-12.8	1.62
MPG Urban	CO Urban	1027	-0.079	6.5	- 8.7	0.75
MPG Urban	NOx Urban	1027	-0.132	10.5	-16.6	1.38
MPG Hwy	HC Hwy	432	-0.035	3.9	-19.3	1.09
MPG Hwy	CO Hwy	432	-0.060	0.9	- 3.5	0.35
MPG Hwy	NOx Hwy	432	-0.071	8.7	-15.2	1.48

The average sensitivity coefficients are small and the standard deviations are large. This means that for all practical purposes, the average sensitivity coefficient is neither positive nor negative, it is zero, meaning that as often as fuel economy goes up when emissions go up, the opposite case happens. If anything, the fact that 5 out of the 6 average sensitivity coefficients were negative would lead one to suspect that the relationship hinted at was one of "emissions down-fuel economy up". However, what is concluded is that the sensitivity coefficient study did not discover any relationship between fuel economy and emissions. If anything, given the data in the above table, it almost appears as if the results might be from independent parameters, i.e. two independent parameters randomly varying.

Section IV. H. Data Stratification By Emission Control System

As a first step in the analysis, each of the three fuel economies (UMPG, HMPG, and CMPG) were plotted against each of the three regulated emissions (FTPHC, FTPCO, and FTPNOX) as well as against the three emissions from the highway test cycle (FEHC, FECO, and FENOX). The data examined were restricted to:

1. Test data generated at EPA's laboratory (the CERT/EPA data base) to eliminate any possible variation due to differences in laboratories,
2. Spark-ignition vehicles (i.e., no Diesels),
3. 1979 through 1981 model year vehicles, in order to make the analysis more relevant to present and future vehicles, and
4. Non-durability vehicles, since durability vehicles with test data up to 50,000 miles and without any matching highway test data were of limited usefulness in this analysis.

However, this first set of 18 graphs (see appendix 4 for similar graphs) did not indicate any relationship between fuel economy and exhaust emissions. This result was expected since regressions of fuel economy against each emission produced very small values of r-squared. (See section IV. A.) Since the highway fuel economy (HMPG) had a weaker relationship to the regulated emissions (FTPHC, FTPCO, FTPNOX) than did either the urban fuel economy (UMPG) or the combined fuel economy (CMPG), subsequent analyses were restricted to trying to relate UMPG or CMPG to FTPHC, FTPCO, or FTPNOX.

The next step was to stratify the data by the emission control technology employed. The following eight (8) emission control systems were identified which are representative of a majority of the systems that are currently in use as well as the ones which will be used in the near future:

Emission Control Technologies

	Fuel Injected	EGR?	Ox Cat?	3 Way Cat?	3CL?	Air Pump?	Pulsating Air Sys?
System 1	No	Yes	Yes	No	No	No	Yes
System 2	No	Yes	Yes	No	No	No	No
System 3	No	Yes	Yes	No	No	Yes	No
System 4	No	Yes	Yes	Yes	Yes	Y/N*	Y/N
System 5	No	Yes	No	Yes	Yes	Y/N	Y/N
System 6	No	Yes	Y/N	Yes	No	Yes	No
System 7	Yes	No	Y/N	Yes	Yes	Y/N	Y/N
System 8	Yes	Yes	Y/N	Yes	Yes	Y/N	Y/N

---

* Y/N means either Yes or No.
(Note: While the above eight systems are non-overlapping, they do not represent all technologies.)

Stratifying the data by emission control technologies increased the number of graphs by a factor of 8 and accordingly decreased the amount of variation. These graphs showed a slight tendency for an increase in fuel economy with a decrease in emission levels; however, since that tendency might have been a result of ETW or transmission differences, further analysis was carried out. Since it was possible that much of this variation was due to differences in the test weight (ETW) of the vehicles, fuel economy results were plotted against the emissions and stratified by both ETW and emission control technologies. However, this approach produced too many graphs, most of which lacked a sufficient number of points upon which to make a statistically sound analysis.

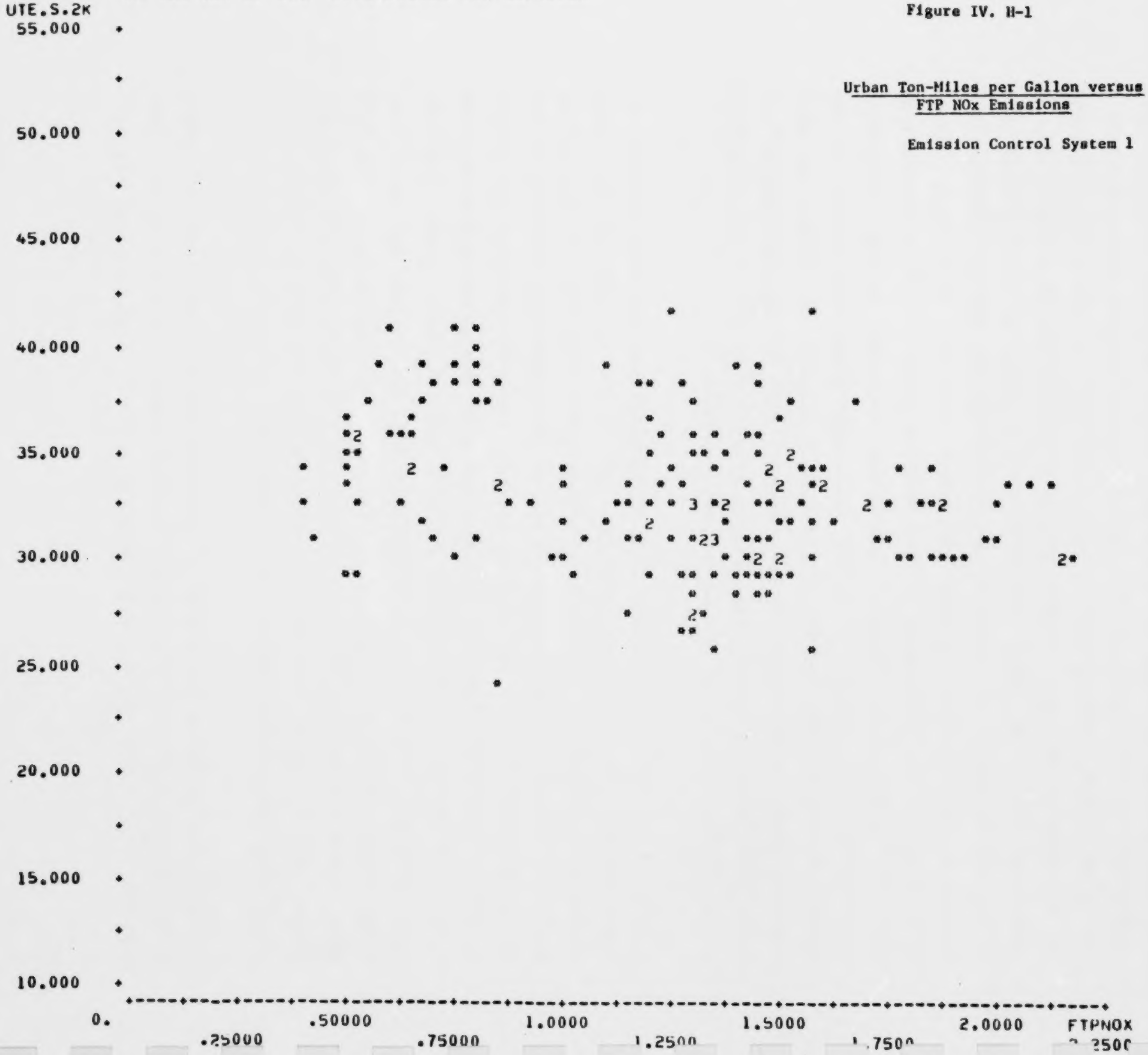
In order to incorporate both ETW and the emission control technology but still have enough data per graph to analyze, the data were stratified by only the technology and then a new variable was plotted. The new variable was fuel economy multiplied by ETW and divided by 2000 (i.e. ton-miles per gallon). This new variable was plotted against each of the three urban emission results. This ton miles per gallon variable is essentially a measure of efficiency for the vehicle. By using this variable, we were able to reduce much of the variation in fuel economy caused only by differences in ETW. Stratifying by control system produced a set of 48 graphs. The graphs for UMPG vs FTPNOX are presented in figures IV. H-1 through IV. H-8. The remaining 40 graphs are in appendix 9. An additional set of 48 graphs was created by plotting gallons per ton-mile (i.e., the reciprocal of ton-miles per gallon) against each of the regulated emissions. These graphs suggested that these variables, which are a measure of efficiency, are independent of the emission results. If we assume that each of these data points represents vehicles having acceptable driveability, then there is little difference among the groups in the minimal levels of FTPHC and FTPCO attainable. However, for FTPNOX, the fuel injected, 3-way, closed-loop vehicles attain 1/3 to 1/2 the emissions of the carbureted, 3-way vehicles, which attain about 1/2 to 2/3 of the emissions of the carbureted vehicles without a 3-way catalyst.

A fifth set of 138 graphs related fuel consumption per ton (i.e. gallons per ton-mile) for the urban and combined test cycles to each of the three regulated emissions and stratified by transmission class (CA, CM, and LA) as well as by control system. A similar set of 132 graphs (see appendix 10 for the graphs which contain at least 12 points), relating ton-miles per gallon to each of the three regulated emissions and also stratified by transmission class, was generated. This sixth analysis had six fewer graphs than the fifth analysis because the sixth analysis did not include any test data prior to the 1980 model year while the fifth analysis additionally used 1979 data. These two analyses confirmed the conclusions drawn from the third and fourth sets of graphs; that is, the efficiency of the vehicle (as measured in ton-miles per gallon) appears to be independent of the emission results.

To assist in analyzing the graphs of ton-miles per gallons versus the urban emissions, the upper and lower ranges on each graph were sketched in. (see appendix 10). These curves were drawn by visual inspection and are not

SCATTER PLOT <1> SYS1T08:1 CASES=TAYR:(79-81)
N= 184 OUT OF 245 41.UTE.S.2K VS. 3.FTPNOX

Figure IV. H-1



Urban Ton-Miles per Gallon versus FTP NOx Emissions

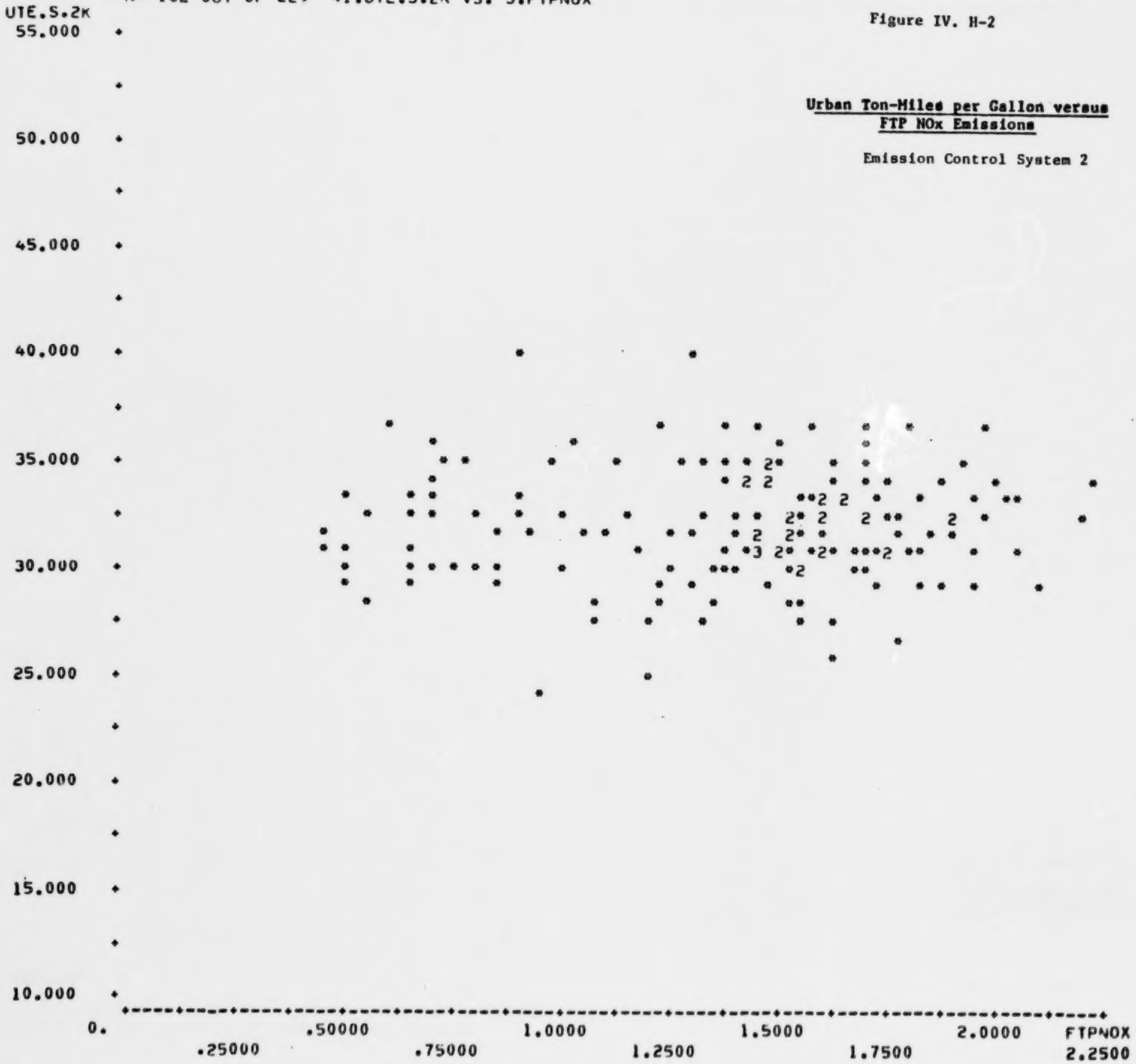
Emission Control System 1

```
SCATTER PLOT  <2> SYS1T08.2  CASES=TAYR:(79-81)
          N= 162 OUT OF 229   41.UTE.S.2K VS. 3.FTPNOX
```

Figure IV. H-2

Urban Ton-Miles per Gallon versus FTP NOx Emissions

Emission Control System 2

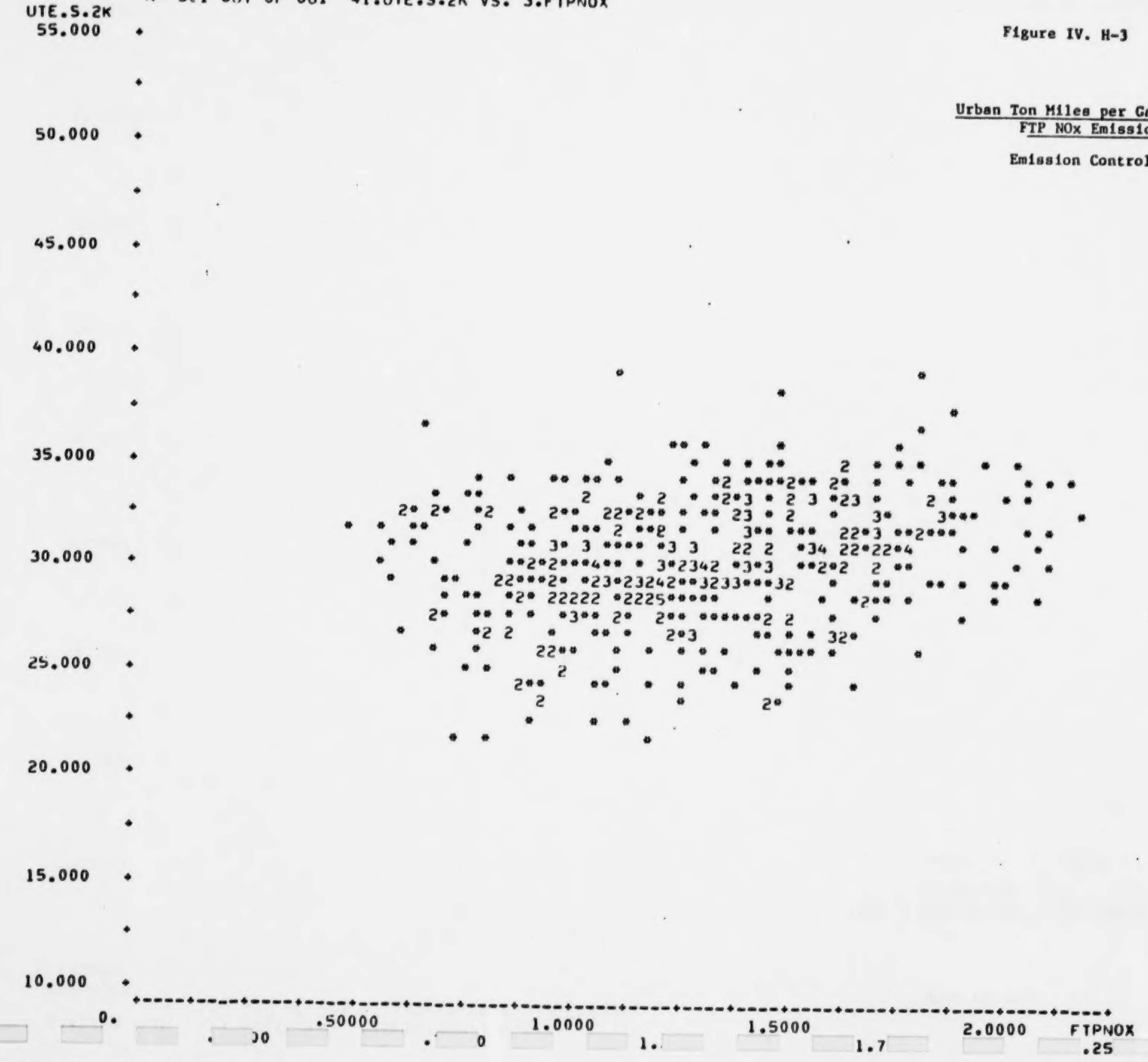


```
SCATTER PLOT  <3> SYS1TOH!3  CASES=TAYR!(79-81)
          N= 501 OUT OF 661   41.UTE.S.2K VS. 3.FTPNOX
```

Figure IV. H-3

Urban Ton Miles per Gallon versus
FTP NOx Emissions

Emission Control System 3



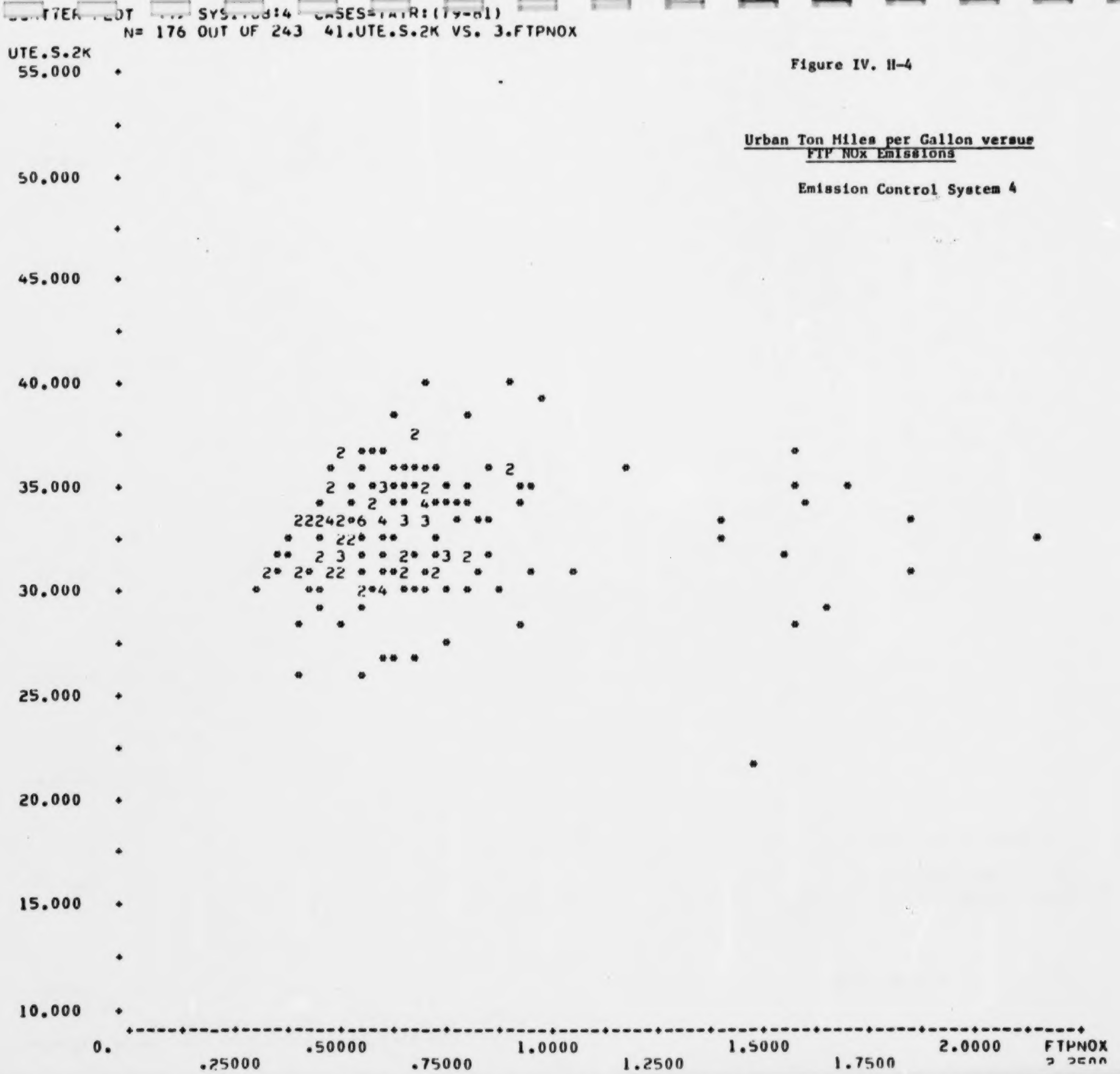


Figure IV. II-4

Urban Ton Miles per Gallon versus FTP NOx Emissions

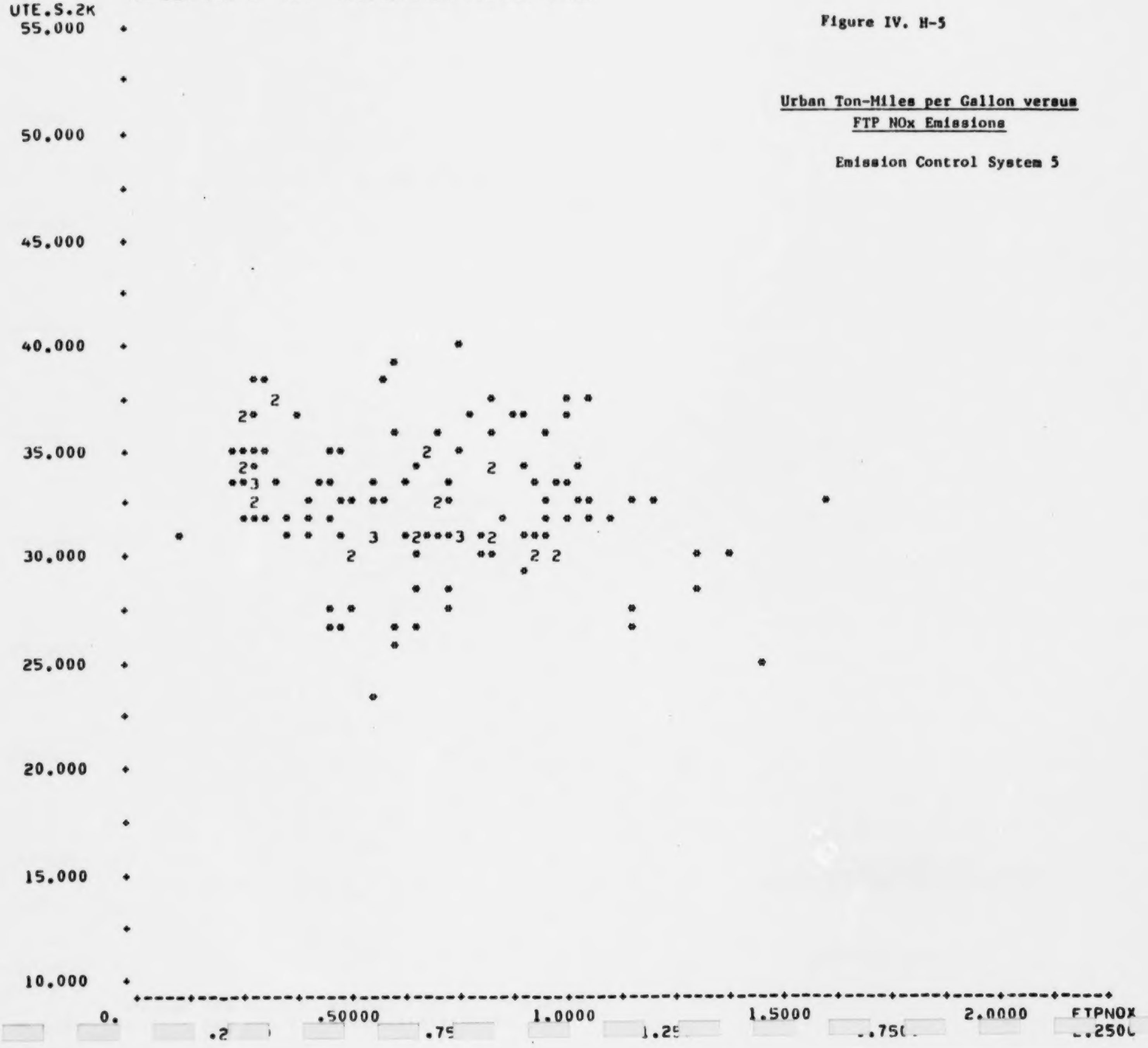
Emission Control System 4

```
SCATTER PLOT  <5> SYS1T08:5  CASES=TAYR:(79-81)
          N= 129 OUT OF 164  41.UTE.S.2K VS. 3.FTPNOX
```

Figure IV. H-5

Urban Ton-Miles per Gallon versus FTP NOx Emissions

Emission Control System 5



```
SCATTER PLOT <6> SYS1 06.6  CASES=TAYR:(79-81)
                   N= 65 OUT OF 88  41.UTE.S.2K VS. 3.FTPNOX
```

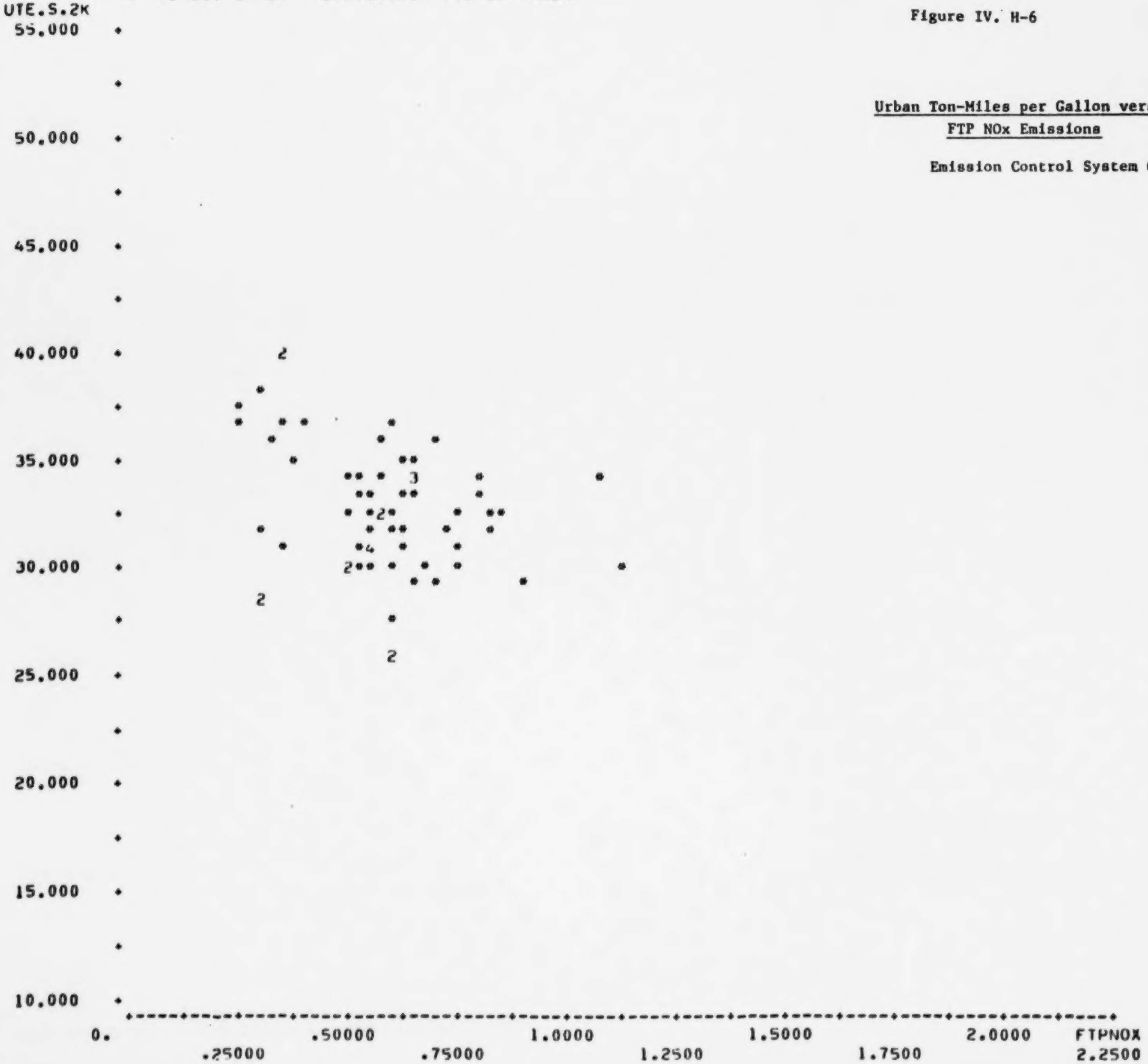


Figure IV. H-6

Urban Ton-Miles per Gallon versus FTP NOx Emissions

Emission Control System 6

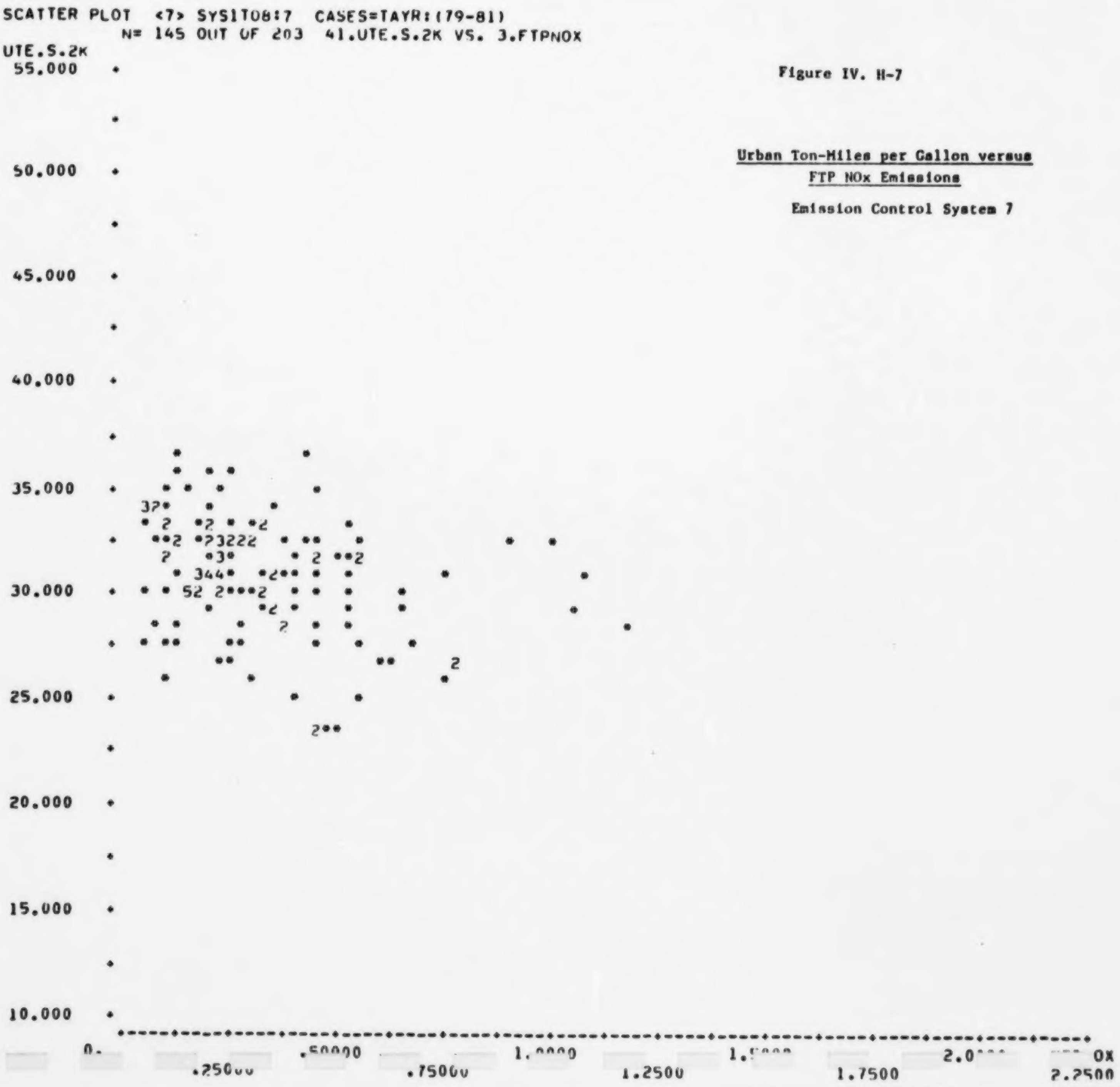


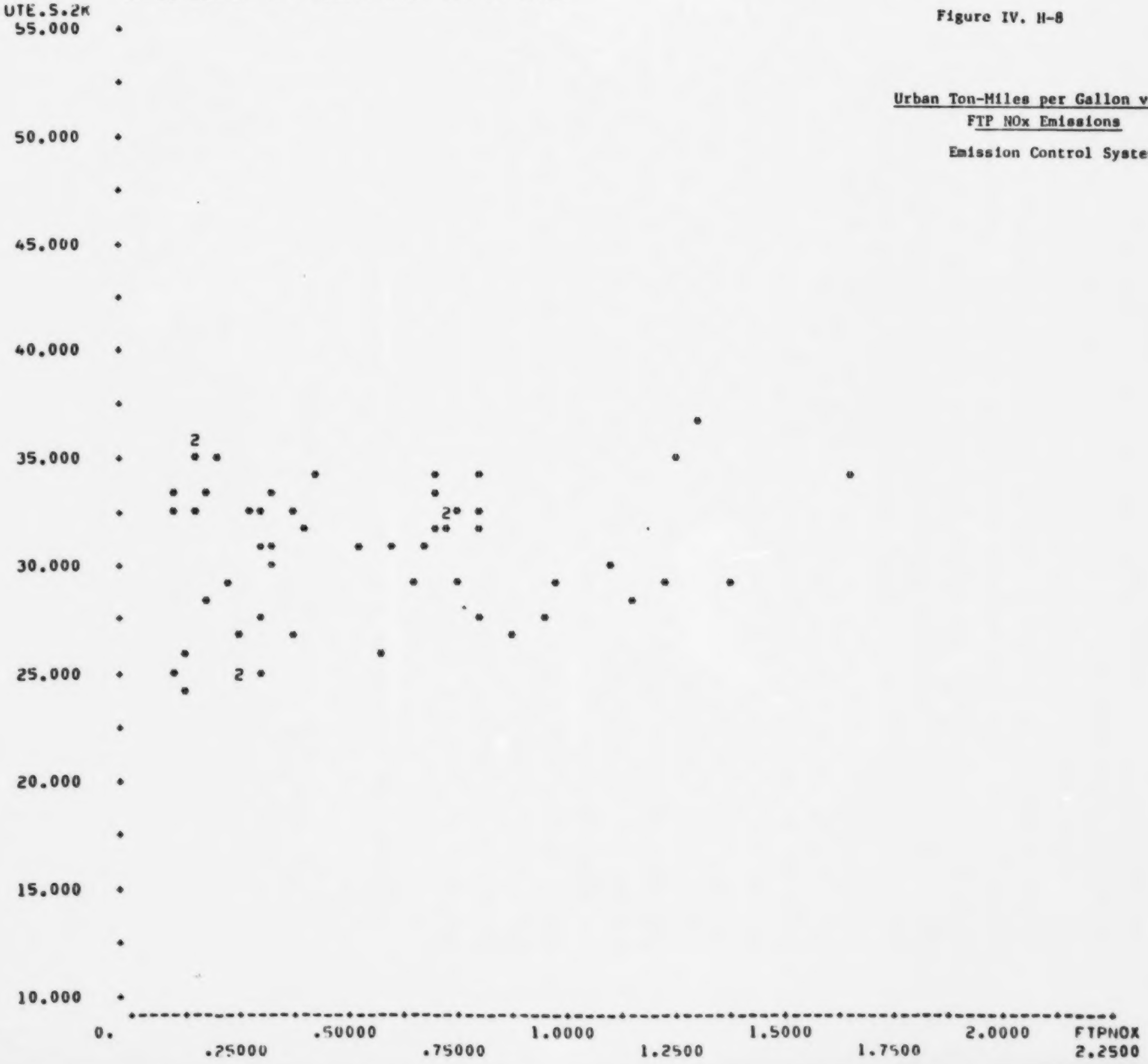
Figure IV. H-7

Urban Ton-Miles per Gallon versus
FTP NOx Emissions

Emission Control System 7

```
SCATTER PLOT  <B> SYS1T0B:8  CASES=TAYR:(79-81)
          N= 55 OUT OF 78  41.UTE.S.2K VS. 3.FTPNOX
```

Figure IV. H-8



<u>Urban Ton-Miles per Gallon versus</u>
<u>FTP NOx Emissions</u>

Emission Control System 8

meant to represent a specific functional relationship between fuel economy and emissions; they are meant only to indicate upper and lower bounds for any such functional relationship that may exist. The plots were then compared to determine whether a given system yielded superior performance (i.e. higher ton-miles per gallon at every level of a given emission). (See figure Toyota -1 in section V. D. for an idealized relationship between systems.) The only such instance we detected was that system number 1 produced higher ton-mile per gallon results at given emission levels than did system number 3. It may be possible that relationship resulted from the smaller parasitic horsepower loss of the pulsating air system compared to an air pump system.

There is an obvious problem, however, in using ton-miles per gallon to analyze the data; that is, the weight of the vehicle is not the only variable which is changing. To compensate for the diversity in engines, tires, axles, et cetera, the test data were examined in each of the 24 groupings obtained by stratifying by the 8 emission control technology systems and by the 3 transmission classes. Within each of the 24 groups, the mean (average) of each of the following: 1/ETW, dynamometer horsepower (VDHP), engine displacement (DISP), rated horsepower (RTHP), and N/V ratio (NSVR) were calculated. We then used the 1981 Cheng Equation (see section IV. D.) to obtain an "adjusted" fuel economy described by the following equation:

$$\begin{aligned}\text{Adjusted MPG} = {} & \text{Actual MPG} + A\,[\,\text{mean}\,(\text{ETW}^{-1}) - \text{actual}\,(\text{ETW}^{-1})\,] \\ & + B\,[\,\text{mean}\,(\text{VDHP}) - \text{actual}\,(\text{VDHP})] \\ & + C\,[\,\text{mean}\,(\text{DISP}) - \text{actual}\,(\text{DISP})] \\ & + D\,[\,\text{mean}\,(\text{RTHP}) - \text{actual}\,(\text{RTHP})] \\ & + E\,[\text{mean}\,(\text{NSVR}) - \text{actual}\,(\text{NSVR})]\end{aligned}$$

These "adjusted MPG" values are actually the measured fuel economy results plus (or minus) a correction factor, predicted by the 1981 Cheng Equation, which approximate the expected results if all the tests within each of those 24 groups had been performed on vehicles of the same test weight, the same VDHP, the same engine size and power, and the same N/V ratio. We then plotted these adjusted MPG values against the corresponding regulated emissions. (See appendix 11.) Care should be taken in evaluating the results of this procedure. (See the discussion on collinearity in appendix 8.)

In examining the plots of adjusted UMPG versus FTPNOX, it was found that 20 graphs each contained at least 12 points. A (two variable) linear regression analysis was performed for each of those 20 sets of data. The analyses indicated that 10 sets of data displayed a tendency for the adjusted UMPG to decrease as the NOx emissions decreased. The other 10 sets displayed the opposite (i.e., the tendency for the adjusted UMPG to increase as the NOx emissions decreased). A similar analysis was performed with graphs of adjusted CMPG versus FTPNOX. In 19 cases, with at least 12 data points, 11 exhibited a tendency for decreases in adjusted CMPG as the FTPNOX decreased, while the remaining 8 exhibited the opposite tendency. Thus, the results from this approach tend to imply that decreasing the level of FTPNOX emissions has no consistent effect on fuel economy.

A visual inspection of the 48 graphs of adjusted fuel economy versus FTPNOX exhibited some patterns which corresponded to figure Toyota-1 (section V.D.). Specifically, it was found that carbureted vehicles equipped with 3-way catalysts (system numbers 4, 5, and 6) produced higher adjusted fuel economy (both urban and combined) results than did carbureted vehicles equipped with air pumps but without 3-way catalysts, for every transmission grouping. This visual analysis also supported the conclusion made earlier in this section that, among carbureted vehicles without 3-way catalysts, those vehicles equipped with pulsating air systems (system number 1) produce higher fuel economies than similar vehicles equipped with air pumps (system number 3).

Another stratification used was to divide the data based on the FTPHC values. Using only the FTPHC test values not exceeding 0.60 grams per mile we grouped the data as follows:

1. HC up to (i.e. less than) 0.20 g/mi
2. HC at least 0.20, but less than 0.30 g/mi
3. HC at least 0.30, but less than 0.40 g/mi
4. HC at least 0.40, but less than 0.50 g/mi, and
5. HC at least 0.50, but less than 0.60 g/mi.

In this last stratification, the attempt was to stratify by both the 8 emission control technology systems and the 5 FTPHC ranges, and then, for each of those 40 groups, plot urban ton-miles per gallon versus FTPNOX. Linear regression analysis was performed on each of those 40 groups of data. Of the 26 sets of data containing at least 12 points, the analysis indicated that 10 sets of data displayed a tendency for decreasing vehicle efficiency with decreasing FTPNOX, and the remaining 16 displayed a tendency for increasing vehicle efficiency with decreasing FTPNOX.

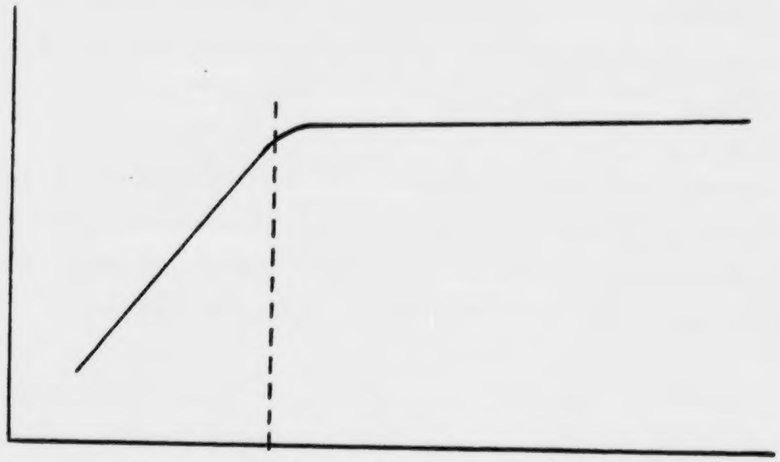
Section IV. I. Is There a "Knee" in the Relationship between Tailpipe Emissions and Fuel Economy?

We will refer to a graph as possessing a "knee" (or "tolerance point") if:

1. To the right of the knee, the graph is almost horizontal, and

2. To the left of the knee, the graph is angled downward sharply.

An idealized sketch of such a graph is:



Since many manufacturers have alluded to the existence of such a curve in relating fuel economy to emissions (usually FTPNOX), the graphical analyses in Section IV. H. were investigated for the existence of such a relationship. While such a "knee" curve might exist, its existence was hidden by the variation among the test vehicles (i.e., differences in ETW, VDHP, DISP, RTHP, and NSVR). However, since the graphs of "Adjusted" fuel economy versus FTPNOX were designed specifically to compensate for those vehicle differences, those 48 graphs were re-examined.

There were several graphs for which could be inferred, from a visual inspection, that decreasing the FTPNOX emissions had a significant effect on the fuel economy. These particular graphs each seemed to possess a "tolerance point" with the following property: for FTPNOX emissions higher than that point, the adjusted fuel economy was unaffected by variations in the FTPNOX level; however, for FTPNOX emission below that tolerance point, the adjusted fuel economy exhibited a significant deterioration with decreasing FTPNOX levels. The groups for which these tolerance points were found are:

1. Carbureted vehicles with lockup automatic transmissions (LA) and oxidizing catalyst systems exhibited a tolerance point at 1.0 NOx for the adjusted UMPG graphs. However, this pattern did not appear on the adjusted CMPG graphs for these groups.

2. For carbureted vehicles equipped with an oxidation catalyst, a 3-way, closed-loop system (i.e., system number 4), and with a manual transmission (CM), a tolerance point of 0.8 g/mi NOx appeared for both the adjusted UMPG and adjusted CMPG.

3. For fuel injected vehicles with EGR and 3-way catalysts (i.e., system number 8), equipped with other than a lockup transmission (i.e., either CA or CM), the adjusted UMPG exhibited a tolerance point at 0.4 g/mi NOx. This same tolerance point (i.e. 0.4 g/mi NOx) also appeared for the adjusted CMPG for only the manual transmission.

These groups represent a very small proportion of the total number of emission control/transmission combinations. Tolerance points were not found for the majority of the combinations. It is interesting to note that the above three tolerance values approximately coincided with actual NOx emission standards (1.0, 0.7, and 0.4 g/mi). However, in order for a test to pass the applicable emission standard, its FTPNOX level multiplied by the appropriate deterioration factor (DF) must not exceed the standard. Since the data used in this section represented low mileage data only, directly relating these data to existing or future standards is not straightforward.

SECTION V.

V. Individual Manufacturer Discussions

V. A. General Motors

1. GM Statements Concerning the Relationship between Emissions and Fuel Economy

In a paper titled "Automotive Fuel Economy Review,"* GM said that emission standards penalized fuel economy in the following manner.

> While we are meeting the 1980 Fuel Economy Standards, which is 20 miles per gallon, we also have to overcome a penalty estimated at up to 5 percent imposed by the increased stringency of the 1980 emission standards. In 1981, when the corporate average fuel economy must be 22 MPG, another increase in emission controls severity imposes an estimated 3 percent penalty on fuel economy as compared with 1979. Introduction of the new GM C-4 Emissions Control System in 1981 will prevent this loss from being larger.
>
> In the preceeding years, compromises in spark and carburetor settings for emission control had reduced GM's new car average fuel economy to 12.0 miles per gallons (mpg) in 1974. Adoption of a new emission control system made possible engine operating improvements that brought average fuel economy up to 15.3 mpg in 1975. The reason was that the use of the oxidizing catalyst to remove most of the hydrocarbons (HC) and carbon monoxide (CO) after the exhaust gases have left the engine enabled us to recalibrate the ignition and carburetion nearer to their optimum settings. Each year thereafter has seen further increase in our fuel economy, so the GM sales-weighted average for 1980 is estimated at 21.4 mpg, an improvement of more than 78% since 1974.
>
> Improved basic engine efficiency also is constantly being sought in research programs. Engine efficiency will be further improved by increasing use of electronic engine controls, to decrease emissions and offset much of the fuel economy penalty resulting from emission control.
>
> It has been a well established fact that the Diesel engine is superior to the gasoline engine in fuel economy, and GM introduced the Diesel engine as an option for its full size Oldsmobile in 1978. For a comparable performance, the Diesel

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* Earl K. Werner, General Motors, "Automotive Fuel Economy Review", Society of Plastics Engineers National Technical Conferences, November 7, 1979, pages 2, 5, 6 & 8.

> gives upwards of 25 percent better fuel economy than the gasoline engine, and if we can overcome the negative effect of tightening emission standards, we expect to apply the Diesel to a greater number of our vehicles, further improving our CAFE.

In a September 22, 1980 letter* to the Administrator of the Environmental Protection Agency, General Motors included a chart which among other things provided information on the effects of emission standards on fuel economy. This information can be found in tables GM-1 and GM-2.

Six CO waiver applications from GM were decided between September 5, 1979 and March 3, 1981. Fuel economy was one of the criteria for granting a CO waiver, yet GM did not make an issue of fuel economy in their first four CO waiver applications. However, in their fifth and sixth CO waiver requests (1.8/2.0 L and 1.6L engines), GM claimed the following:

> Compliance with the 3.4 gpm CO standard as compared to a 7.0 gpm CO standard has the potential of adversely affecting fuel economy in the range of 2 to 5 percent, citing engine calibration changes ("retuning") as one of the principal causes.
>
> To further substantiate its position, General Motors embarked on an engineering development and test program in which a "J" car 1.8L engine was calibrated to meet the 3.4 gpm CO standard and then recalibrated to meet a 7.0 gpm CO standard. Exhaust emissions and fuel economy were measured under both conditions and driveabilty was compared. The results of these tests have been presented to EPA for the public record. These results show that a fuel economy penalty of 1 mpg would exist in the EPA label value if the waiver were denied.
>
> To further substantiate the fuel economy penalty, we have now completed an investigation involving a matched pairs study of federal gasoline passenger cars comparing the fuel consumption improvement from 1980 to 1981 of those passenger cars granted the CO waiver to the fuel consumption improvement from 1980 to 1981 of those [Federal gasoline] passenger cars not granted the CO waiver. This study was based on the premise that any improvement in fuel consumption between the CO and non-CO waiver groups could be attributed to the CO waiver. The following parameters were matched: engine displacement, test weight, transmission, axle ratio and dynamometer horsepower setting. The results are shown in [table GM-3]:**

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* Letter and enclosures to the Honorable Douglas M. Costle, Administrator, U.S. Environmental Protection Agency from Dr. Betsy Ancker-Johnson, General Motors, dated September 22, 1980.

** Letter and attachment to Mr. D.M. Costle (Administrator, EPA), from T. M. Fisher (GM), dated December 8, 1980.

Table GM-1

GENERAL MOTORS CORPORATION

LIGHT DUTY (PASSENGER CAR) GASOLINE ENGINES

Issued: October 1, 1980

EFFECTS OF EXHAUST AND EVAPORATIVE EMISSION STANDARDS ON HARDWARE, FUEL ECONOMY, FUEL CONSUMPTION, AND ADDITIONAL-FIRST-COST TO CONSUMER

NOTE: The data in this table are based on tests of current GM hardware designed to comply with light duty (passenger car) gasoline emission and fuel economy standards. Hardware utilized in this effort has an effect on performance in both areas, although installed primarily for its contribution to either emission control or fuel economy. Since the "state of the art" in this effort has changed rapidly, it should be noted that the hardware and cost estimates represent current technology adjusted to reflect 1981 economic levels and new 1981 average dealer discounts. As a result, it should be expected that future versions of this table may not be the same as shown here. This table will be updated periodically.

Standards HC/CO/NOx/Evap.	Applicable/ Most Probable Hardware[1]	Fuel Economy Loss, Percent[2]	Increased Fuel Consumed in Vehicle Life Billions of Gallons[3]	Gasoline Vehicle First Costs, $[4]		Remarks
				Add'l	Total	
1.5/15/2.0/6.0 1979 Federal	Oxid. Conv., EGR or BPEGR,	Baseline	Baseline	Baseline	185	For each set of future standards, the tabulated results are based on comparisons between vehicles meeting the 1.5/15/2.0/6.0 standards and comparable vehicles equipped with hardware designed to meet the future standards.
.41/7.0/2.0/6.0 1980 Federal	Oxid. Conv., AIR or PAIR, BPEGR	3	1.0	60	245	
.41/9.0/1.0/2.0 1980 California	CCC Sys. (Single Bed), AIR, BPEGR	2-3	Included Above	475[5]	660[5]	Dual-bed CCC systems and EST received limited use in California in 1980 to gain field experience with these advanced technologies. Additional vapor storage capacity and improved fuel system seals were required to meet the 1980 California evaporative standard (same as the 1981 Federal standard).
.41/3.4/1.0/2.0 1981 and Later Federal	CCC Sys. (Dual-Bed), AIR, BPEGR, EST, ISC	Minimum of 1	2.1	540[6]	725[6]	In general, a dual bed CCC system is necessary to provide the improved CO control necessary to meet a 3.4 g/mile standard. A limited number of engine families have been granted a waiver to a 7.0 g/mile CO standard for 1981-82.
.41/3.4/.41/2.0 Research Objective	CCC Sys. (Dual-Bed), AIR, BPEGR, EST, ISC, and ?	?	?	?	?	Meaningful assessments of fuel economy and additional first cost cannot be made since control systems have not been demonstrated to meet these standards through the complete EPA 50,000-mile certification durability requirements, selective enforcement audit and in-use surveillance requirements.

[1] Hardware Definitons: (a) EGR - Exhaust Gas Recirculation, (b) BPEGR - Back Pressure EGR, (c) AIR - Air Injection Reactor, (d) PAIR - Pulse Air Injection Reactor, (e) CCC System - Computer Command Control System, (f) Single-Bed - 3-Way Catalyst, (g) Dual-Bed - 3-Way Catalyst plus Oxidation Catalyst, (h) EST - Electronic Spark Timing, and (i) ISC - Idle Speed Control. Other electronic engine controls may be included if emission control or fuel economy benefits are demonstrated.

[2] Fuel Economy: The use of a diesel engine of comparable performance in place of a gasoline-fueled engine, may increase the fuel economy of that vehicle by about 25-30%. Refer to other side for diesel information.

[3] Fuel Consumption: Based on emission certification and fuel economy tests, a fuel economy penalty of 3% has been determined for 1980 vehicles and 1% estimated for 1981-1985 vehicles to project the increase in total fuel consumed during the life of 1980 through 1985 vehicles, in comparison to vehicles meeting the future fuel economy standards. Total fuel consumed was calculated using the General Motors fuel consumption model. These fuel economy penalties result in an increase in total fuel consumed of 3.1 billion gallons of fuel during the life of 1980-1985 vehicles.

[4] Hardware Costs: On-going production costs of 1979 gasoline vehicle exhaust emission control systems was $165, in comparison to uncontrolled vehicle costs; evaporative emission controls cost an additional $20 for a total gasoline vehicle baseline cost of $185. Additional first costs of future systems are estimated on the basis of system definitions as of August, 1980. For vehicles equipped with a CCC system, the oxygen sensor may have to be changed during the useful life of the vehicle, at an additional maintenance cost.

[5] California 1980 Hardware Cost: The cost data shown are calculated on the basis of high volume production and therefore are conservative estimates. Compared to 1981 and Later Federal, 1980 California costs include compliance testing.

[6] Future Cost Trends: Based on projections of potential reductions of electronic component costs, first cost to the consumer is expected to decrease in later years from the value given in the table.

AEC185
9/15/80

Table GM-2

GENERAL MOTORS CORPORATION

LIGHT DUTY (PASSENGER CAR) DIESEL ENGINES

Issued: October 1, 1980

ESTIMATED EFFECTS OF EXHAUST AND EVAPORATIVE EMISSION STANDARDS ON POTENTIAL HARDWARE, AND ADDITIONAL-FIRST-COST TO CONSUMER

NOTE: The projections in this table are based on tests of current GM experimental hardware and advanced research on control concepts which may have potential for compliance with future emission and fuel economy standards[4]. NO ADVANCED HARDWARE BEYOND 1982 FEDERAL HAS DEMONSTRATED AN ABILITY TO ACHIEVE FUTURE STANDARDS. The control hardware listed below represents GM's best ESTIMATE of the TYPE and EXTENT of the hardware that will be necessary to approach future standards, and should not be interpreted to mean that the needed technology is available. This table will be updated periodically to reflect changes in the "state of the art."

Event	Standards[5]			PART-ICULATES	Applicable/Most Probable Hardware[2]	Diesel First Add'l	Vehicle Cost $[3] Total	Remarks
	HC	CO	NOx					
1979 Federal	1.5	15	2.0		Baseline Uncontrolled Engine	Base-line	Base-line	Same engine marketable nationwide in 1979.
1980 Federal	0.41	3.4	2.0 [sic]		F.I. Timing, EGR	50	50	1980 California diesel engine certified to 1.5 NOx standard with 100,000 mile durability requirement (See footnote 1).
1981 Federal	0.41	3.4	1.0* *Waived to 1.5		F.I. Timing, MOD-EGR	50	50	*Waived to 1.5 NOx is available for 1981-84 with EPA approval. GM 5.7 L diesel granted waiver to 1.5 NOx for 1981-82. Redesign of EGR system offsets potential hardware cost increase of more stringent NOx standard.
1982 Federal	0.41	3.4	1.0* *Waived to 1.5	0.6	F.I. Timing, MOD-EGR	50	50	First application of particulate requirement. No specific additional hardware deemed necessary for compliance.
1982 California	0.54	7.0	1.2	0.6	F.I. Timing, analog electronic control of EGR and TCC engagement	Undetermined[3]		NOx standard for turbocharged engines = 1.5 gpm NOx at 100,000 miles. NOx standards were set by CARB emergency action and are subject to confirmation at public hearing. 0.57 HC standard reflects adjustment for low evap. allowance.[1,5] This system would be required to meet 1983 Federal Standards w/o NOx waiver.
1984 Federal	0.41	3.4	1.0*	0.6	Digital electronic control of EGR, F.I. Timing, rich fuel limiter and TCC engagement. Modified F.I. Pump.	Undetermined[3]		Compliance required 1984 and beyond at all altitudes.
	0.41	3.4	1.0	0.2	Digital electronic control of EGR, F.I. Timing, rich fuel limiter and TCC engagement. New electronic controlled F.I. Pump. Some form of regenerative particulate trap is required.	Undetermined[3]		TECHNOLOGY IS NOT AVAILABLE TO CONTROL EMISSIONS TO THESE STANDARDS: the hardware described represents one form of research control concept under study. It is impossible to define the extent of development time and effort needed to develop practical and reliable production hardware.

[1] California Standards: Beginning in MY 1980, the California Standards provide a variety of options and adjustments which result in different standards for each consecutive year. Available options include total or non-methane HC standards, 100,000 mile durability standards, HC standard adjustment for low evap. emission systems, and various combinations of these provisions. The difficulty of controlling NOx results in selection of least stringent NOx requirement.

[2] Hardware Definitions: (a) EGR - Exhaust Gas Recirculation, (b) MOD-EGR - Modulated Exhaust Gas Recirculation (c) TCC - Torque Converter Clutch (transmission), (d) F.I. - Fuel Injection, (e) Rich Fuel Limiter - a control that holds air/fuel ratio below some level of enrichment. Emission Control hardware is not yet defined beyond 1981, although speculation as to the general concepts necessary to fulfill minimum need is possible as shown.

[3] Hardware Costs: Since control hardware is undefined beyond 1982 Federal Standards, projection of first costs of future systems is not possible at this time. Costs shown are expressed in 1981 dollars.

[4] Fuel Economy: The use of a diesel engine of comparable performance in place of a gasoline-fueled engine, may increase fuel economy of that vehicle by about 25-30%. Refer to other side for gasoline information.

[5] Evaporative Emissions: Diesel-fueled vehicles typically do not emit significant amounts of hydrocarbons through evaporative or refueling mechanisms. Consequently, compliance with the 2.0 g per test evap requirement is possible without additional hardware.

AEC199

Table GM-3

Percent Improvement in Fuel Consumption of 1981 Federal Passenger Cars Compared to 1980 Federal Passenger Cars**

Classification	Average Adjusted GPM Improvement Between 1980 and 1981	% Improvement From 1980 to 1981	Number of Combination Groups Matched
All Federal Passenger Car Engines	.0012	2.6%	28
CO Waiver-Engines	.0022	4.7%	10
Non-CO Waiver Engines	.0007	1.4%	18
Difference Between the CO Waiver Engines and the Non-CO Waiver Engines	.0015	3.2%*	--

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* A 95% confidence interval was calculated for the difference of two means with common unknown variances. The confidence interval ranges from -1.5% to 7.9%.

These data clearly indicate that those vehicles granted the CO waiver exhibit a 3.2% increase in fuel economy over those vehicles without the CO waiver. This finding compared favorably with both the National Research Council's estimate of 2 to 5 percent and with our experience on the "J" car test program as well.

** Retyped for clarity.

> Coincidentally, as part of a new application being submitted today for a 1982 CO waiver on the 1.6L Chevrolet Chevette engine, we have conducted a test program similar to that conducted on the "J" car as described above. The data from the Chevette testing also confirms a fuel economy penalty on the order of 1 mpg for a car complying with a 3.4 gpm CO standard as compared to a car complying with a 7.0 gpm standard. These data are enclosed in the attachment [table GM-4].
>
> All of these data consistently show that, without a waiver, the "J" car 1.8/2.0 liter engine family will achieve lower fuel economy levels than it could have achieved were a relaxed CO standard in effect. Based upon our best estimates, we believe a fuel economy penalty of the magnitude of 1 mpg on the EPA label will cause a significant number of potential buyers to either purchase a competing model of vehicle, or to withdraw from the new car market place until better fuel economy is achieved to help offset the cost of the new car. In either case, the effect is one of lost sales to General Motors.

In a report to EPA, GM said "a 0.4 g/mi NOx standard would worsen fuel economy and driveability of gasoline engines, and, at present levels of technology, it would eliminate the fuel-efficient Diesel..."*

Automotive News said "GM also stressed that averaging and lowering emission standards may improve fuel economy."**

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* General Motors, "1979-1980 Report of General Motors On Advanced Emission Control System Development Progress," February, 1981, Vol. 1, page 9.

** Automotive News, April 6, 1981, page 49.

Table GM-4

ATTACHMENT

COMPARISON OF EMISSION AND FUEL ECONOMY RESULTS FOR DEVELOPMENT DATA CARS EQUIPPED WITH 1.6 LITER ENGINES AND CALIBRATED TO 3.4 AND 7.0 G/MI CO STANDARDS

	Car Calibrated to 3.4 g/mi Standard*			Car Calibrated to 7.0 g/mi Standard**		
	Test 1	Test 2	Avg.	Test 1	Test 2	Avg.
Automatic Transmission Equipped Cars (IT035A and IT035B)						
Emissions (FTP) g/mi						
HC	.087	.077	.082	.154	.195	.174
CO	.90	1.21	1.06	3.06	4.01	3.54
NOx	.32	.29	.30	.23	.33	.30
Fuel Economy mpg						
City	22.9	23.2	23.05	24.0	23.7	23.85
Highway	27.3	27.9	27.60	30.0	30.2	30.10
Composite	—	—	24.90	—	—	26.31

	Car Calibrated to 3.4 g/mi Standard*					Car Calibrated to 7.0 g/mi Standard**			
	Test 1	Test 2	Test 3	Test 4	Avg.	Test 1	Test 2	Test 3	Avg.
Four-Speed Manual Transmission Equipped Cars (IT033A and IT033B)									
Emissions (FTP) g/mi									
HC	.075	.084	.077	.084	.080	.137	.115	.118	.123
CO	.99	1.12	.42	.84	.84	2.26	1.94	1.86	2.02
NOx	.31	.33	.24	.26	.28	.52	.36	.35	.41
Fuel Economy mpg									
City	24.9	25.2	25.1	25.3	25.13	26.4	26.0	26.1	26.16
Highway	33.5	33.8	33.6	—	33.63	34.9	34.5	34.6	34.66
Composite	—	—	—	—	28.35	—	—	—	29.40

Notes:

* Calibrated using deterioration factors (HC - 1.419, CO - 1.590 and NOx - 1.285) developed on certification durability car 1110.

** Calibrated using deterioration factors (HC - 1.679, CO - 1.490 and NOx - 1.248) developed on certification durability car 1104.

2. New Technology or Developments which Could Provide a Change in the Relationship Between Emissions and Fuel Economy as Compared to 1981 Vehicles or GM's Estimates

A. The first device discussed is GM's detonation sensor system, which was described in Society of Automotive Engineers Paper #790173, titled "Energy Conservation with Increased Compression Ratio and Electronic Knock Control". The following GM discussion provides; a) insight into the circumstances which led to the development of this system, b) how it operates, and c) test data for two vehicles calibrated to meet 0.41 HC, 3.4 CO and 1.0 NOx, one with the detonation sensor system, and the other, without.

> Spark Knock Control has been the focus of extensive research over the years by both oil companies and engine manufacturers. Efforts to improve the fuel economy and performance of spark ignited gasoline engines have been hindered by the occurence of knock which can be affected by such variables as engine tolerances, fuels, and vehicle operating conditions. In the past, spark knock control has been achieved by the use of fuel additives, fuel blends, or engine design modifications such as combustion chamber design, cooling system design, or retard of ignition timing. Currently, spark retard is utilized in many production engines to reduce the tendency for knock under adverse driving conditions such as heavy load, high ambient temperature, or low humidity. Accordingly, the engine may operate with reduced efficiency under less adverse conditions when retard is not required to control knock. With the advent of catalytic converters necessitating the use of unleaded fuels, the engine designer has limited the compression ratio so that the engine octane requirement is satisfied by the current available unleaded fuels.
>
> Historically, raising the compression ratio of an engine has improved efficiency. However, there has been some concern, in addition to the concern for higher octane requirement that efficiency might not be improved when higher compression ratio engines were recalibrated to meet emission constraints. As a result, a study (1)* was recently completed at General Motors which indicated that with catalytic converter emission control systems, the traditional efficiency gains were possible at the current Federal Exhaust Emission Standards, (1.5 g/mi HC, 15 g/mi CO, 2.0 g/mi NOx) when raising compression ratio from 8.3:1 to 9.2:1.

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* References are listed by the number in parentheses at the end of the excerpts.

This gain was accompanied by an increase in octane requirement, however, which could not be satisfied with 91 Research Octane Number (RON) unleaded fuel. Published information from the petroleum industry indicated that substantial energy losses occurred in the refinery when producing higher octane unleaded fuel. As a result, the energy losses in the refinery for making the higher octane fuels offset the efficiency gains in the vehicle. Consequently, the conclusion of this study was that there did not appear to be an incentive for increasing unleaded fuel octane levels to allow for the use of higher compression ratio engines with a catalytic converter emission control system.

This paper will describe an electronic closed loop knock control system that may satisfy the octane requirements of more efficient higher compression ratio engines, at current (1.5/15.0/2.0) and 1981 exhaust emissions levels (.41/3.4/1.0), with 91 octane fuel.

A knock control system (2) is currently being offered by the Buick Motor Division of General Motors on the Turbocharged V-6 engine. The scope of the paper will, therefore, be limited to the application of the knock control system to higher compression ratio engines.

CLOSED LOOP KNOCK CONTROL (CLKC) SYSTEM DESCRIPTION

The knock control system was designed for use on engines with electronic ignition. It includes a detonation sensor or accelerometer, electronic controller and modified distributor.

The detonation sensor, is mounted on the intake manifold of the engine. The location of the sensor is carefully selected to insure that the knock vibration will be transmitted as equally as possible from all cylinders.

If no knock is present, the normal ignition timing, determined by the basic timing, centrifugal advance, and vacuum advance is passed directly to the distributor. When knock occurs, the detonation signal is larger than the background noise level and a retard command is generated that is proportional to the intensity of knock encountered.

The retard command is used to produce a delayed or retarded ignition pulse to the distributor. The distributor ignition module has been modified to accept the retarded ignition pulse. When knock is reduced to desired levels, the controller restores the spark advance at a predetermined rate until the normal spark values are re-established. It is important to note that the system only retards and does not advance timing to seek out knock.

It can be noted that the spark is retarded rapidly to control knock and then readvanced slowly. This is a feature used to maintain smooth vehicle operation during knock control. More rapid changes in spark timing can cause uneven engine power resulting in surge which is observed by the driver as a jerky forward motion in the vehicle. Throughout the acceleration, the spark advance is retarded and readvanced while the system seeks to maintain a commercial knock level. In this example, the maximum retard for this condition was 11° during the test. The operation of the knock control system is dependent on the occurrence of knock. That is, a knocking cycle must occur to trigger the control system and generate retard. These "knock control" cycles, which occur just prior to control, may be heard as random trace to light knock in the engine during the control mode. It should, therefore, be emphasized that the system does not eliminate detonation, but controls the knock to commercial levels. More sensitive control of detonation below these levels can produce a "false retard" condition when retard occurs without knock in the engine. False retard should be avoided as it can result in a loss of vehicle performance and fuel economy.

The maximum spark retard available using the knock control system is determined by the physical characteristics of the distributor and vehicle driveability. For example, the maximum retard is physically limited by arcing or crossfire in the distributor cap which can result in a spark occurring in the wrong cylinder.

Likewise, large changes in spark retard could also contribute to the surge problem described earlier. The final vehicle spark calibration with a knock control system must, therefore, be evaluated under the most severe knocking conditions expected, to insure that the system has sufficient retard capacity to control knock while maintaining driveability.

FUEL ECONOMY POTENTIAL AT .41/3.4/1.0 EMISSION STANDARDS - Two vehicles (4000 lb. inertia weight) with 305 CID engines and 3-way catalyst emission control systems were built to determine the fuel economy advantage of a higher compression ratio and a closed loop knock control at the 1981 Federal emission standards of .41/3.4/1.0. The engines were built with 8.4:1 and 9.2:1 compression ratios, respectively, and calibrated within the same percent loss (approximately 1%) from best fuel economy spark timing. Both vehicles were equipped with closed loop knock control systems allowing the vehicles to be calibrated without a knock constraint. Fuel economy gains were therefore determined for the effect of compression ratio at equivalent emission levels. Rear axle ratios were selected to equalize the performance of the cars.

Emission Results - Emission targets of .25/2.5/.60 were established to allow for emission control system deterioration, vehicle variability, and test variability. These targets would not necessarily assure that these vehicles would meet the Federal Standards at 50,000 miles, however, since durability testing was not run as part of this program. Figure 13 illustrates that the exhaust emission goals for hydrocarbons, carbon monoxide, and oxides of nitrogen were met with each vehicle. In general, the higher compression ratio engine required more EGR for NOx control and more spark retard during cold start operation for HC control.

FUEL ECONOMY RESULTS - Figure 14 shows the comparison of fuel economy on the EPA city (5) and highway (6) schedules for the 8.4 CR and 9.2 CR vehicles. The 9.2 CR vehicle exhibited a 3.7% advantage in fuel economy on the EPA city test and 5.3% gain on the EPA highway test. The overall fuel economy improvement for the composite 55/45 test was 4.3%. These results were obtained from the average of four tests on each vehicle and were all run with 91 RON fuel.

The fuel economy tests on the 9.2 CR vehicle were then run with clear Indolene test fuel (RON 98). This resulted in a small gain in fuel economy on both the city and highway tests (Figure 24) and the overall gain for the change in compression ratio was 5.9%. The reason for this difference appears to be due to the reduction in spark retard required to control knock with the higher octane fuel on the 9.2 CR vehicles.

Figure 15 illustrates the spark retard generated by the 9.2:1 compression ratio engine on 91 and 98 RON fuels during one of the more severe portions of the EPA city test. The frequency of occurrence of knock and amount of retard required to control knock was greater with 91 RON fuel. The increased retard had a minimal effect on the EPA fuel economy results as the spark was not retarded over the majority of operating conditions. The 8.4 CR vehicle did not have significant spark retard during the EPA test; therefore, no change in fuel economy would be expected due to increasing fuel octane over 91 RON.

305-4
CLOSED LOOP CARBURETOR
1975 FEDERAL TEST PROC.
AVG. 4 TESTS

4000# I.W., 10.8 HP
3-WAY CONVERTER - EGR
91 RON FUEL

		TAILPIPE (GMS/MI)		
C.R.	AXLE	HC	CO	NOx
8.4:1	2.41:1	.25	2.5	.52
9.2:1	2.28:1	.22	2.4	.63
TARGET		.25	2.5	.60
STANDARD		.41	3.4	1.0

Fig. 13 - The exhaust emissions of the 8.4 CR and 9.2 CR vehicles met the target levels for the 1981 Federal standards

305-4
CLOSED LOOP CARBURETOR

4000# I.W., 10.8 H.P.
3 WAY CONVERTER-EGR

AVERAGING OF 4 TESTS

	COMPRESSION RATIO	8.4:1	9.2:1	
	REAR AXLE RATIO	2.4:1	2.28:1	
FUEL	EPA FUEL ECONOMY			% GAIN
91 RON (CHEVRON 91)	CITY	16.1	16.7	3.7
	HIGHWAY	22.7	23.9	5.3
	COMPOSITE 55/45	18.5	19.3	4.3
98 RON (INDOLENE CLEAR)	CITY	-	16.9	5.0
	HIGHWAY	-	24.4	7.5
	COMPOSITE	-	19.6	5.9

Fig. 14 - The 9.2 CR vehicle exhibited a 4.3% gain in fuel economy on the EPA composite 55/45 test

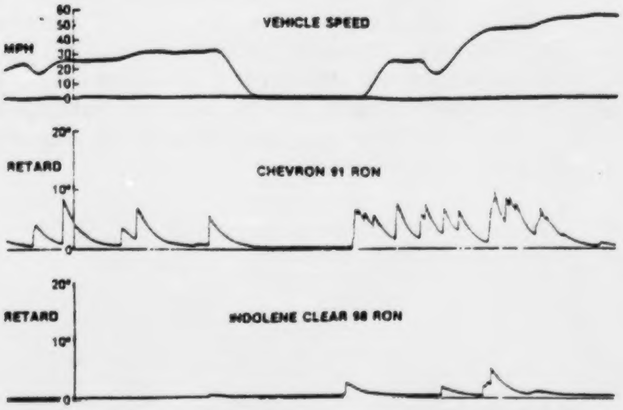

Fig. 15 - The amount of retard encountered by the 9.2 CR vehicle on the EPA City test was reduced when fuel octane was increased from 91 RON to 98 RON

The following references are for the preceding quotations from SAE paper number 790173.

REFERENCES*

1. J.J. Gumbleton, G.W. Niepoth, and J.H. Currie, "Effect of Energy and Emission Constraints on Compression Ratio", Paper 760826 presented at SAE, October 1976.

2. T.F. Wallace, "Buick's Turbocharged V-6 Powertrain for 1978", Paper 780413 presented at SAE, March 1978.

5. R.E. Kruse and T.A. Huls, "Development of the Federal Urban Driving Schedule", Paper 730553 presented at SAE, May 1973.

6. T.C. Austin, K.H. Hellman and C.D. Paulsell, "Passenger Car Fuel Economy During Non-Urban Driving", Paper 740592 presented at SAE, August 1974.

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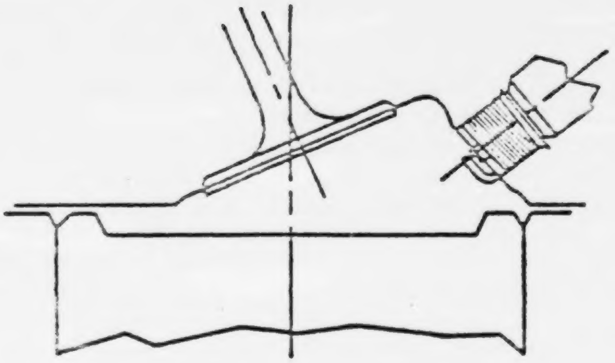
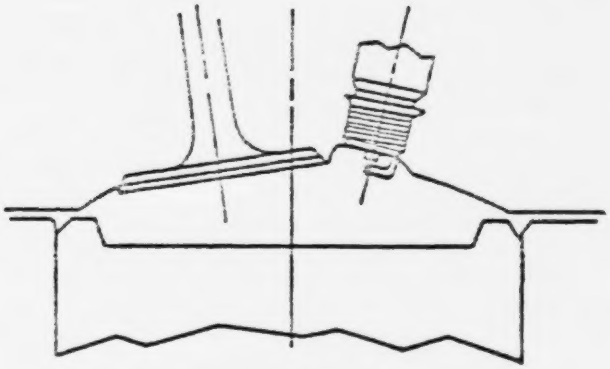
* Only those references which were cited in the previous excerpts were included in this listing. The original reference numbers were used for this document.

B. Another area, which affects the relationship between fuel economy and emissions, is combustion chamber design. GM described development work concerning combustion chambers in the Society of Automotive Engineers Paper #800920, titled "The Attributes of Fast Burning Rates in Engines." The following excerpts from this paper provide insights into combustion chamber design and its effect on the relationship between emissions and fuel economy. The references cited by GM are listed at the end of the excerpts.

> THE CONCEPT OF BURNING THE MIXTURE in a spark ignition engine relatively fast is increasingly making its way into engine designs throughout the world. Fast burning is certainly not new, with the higher efficiency or output and fuel octane advantages being known for decades. In fact, some of the engines of the 1920's (1) incorporated combustion-chamber design features promoting fast burning.
>
> In the past, fast burning was curtailed, due to adverse noise and mechanical failures caused by too great a rate of pressure development, particularly as compression ratios were increased. With the introduction of exhaust gas recirculation (EGR) for oxides of nitrogen control in the early 70's and the lowering of compression ratios in the mid 70's, the pendulum swung the other way, and burning rates decreased sharply. The current movement toward fast burning represents an effort to reestablish, at least to some degree, the rates of combustion that once existed in engines.
>
> ENGINE EFFICIENCY AND EMISSIONS -
>
> Tuttle and Toepel (10) diagnosed and compared combustion in the two different combustion chambers shown in Fig. 8. The wedge chamber, with its off-set spark plug and resulting long flame travel distance, promotes relatively long burning times. In contrast, the compact open chamber, with a more central spark plug, would be expected to produce faster burning. Each combustion chamber was instrumented extensively, including the incorporation of cylinder pressure instrumentation (14-16) to diagnose heat release and flame motion (17). Testing followed a statistical experimental design involving selected combinations of engine speed, fuel input, air-fuel ratio, EGR rate and spark timing.



WEDGE CHAMBER



OPEN CHAMBER

Fig. 8 - Experimental study combustion chambers (10)

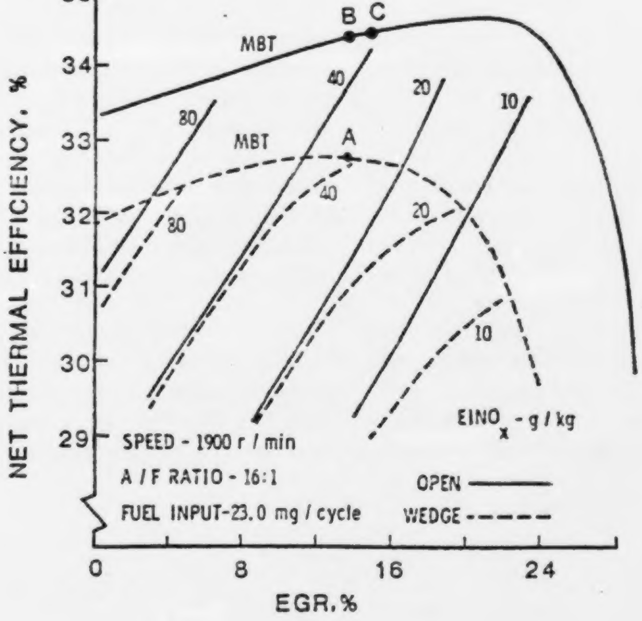


Fig. 9 - Efficiency - NO$_x$ tradeoff (10)

Experimental results showed that the open chamber did indeed have faster burning, as made evident by shorter combustion times and reduced spark-advance values at MBT. Net thermal efficiency of both chambers is shown in Fig. 9 for various amounts of EGR, with engine speed, air-fuel ratio, and fuel input constant. Concentrating first on the curves denoted MBT, which represents optimum timing data, the open, or faster burning chamber, is seen to exhibit higher efficiencies. Starting with no EGR, the efficiency at first increases with the addition of EGR. This behavior is due to both the higher specific-heat ratio and the reduced throttling of the more dilute mixture. .

Another important advantage of the faster burning chamber is its greater tolerance to dilution. As shown, EGR rates as high as 28% can be accommodated with the open chamber, versus 22% for the wedge chamber, before the efficiency drops off significantly. This capability of going to greater dilution with fast burning has also been found (18) to occur when the dilution gas is air rather than EGR.

Also shown in Fig. 9 are lines of constant NO emissions. Movement vertically downward from the MBT line represents increasing spark retard from optimum timing. Evident is the familiar reduction in NO with either spark retard or higher EGR rate. A comparison of the condition at points A and B shows the same trend uncovered earlier using the engine simulation - namely, that faster burning produces higher NO emissions. Note, however, that by adding a slight amount of EGR to the open chamber (point C), its efficiency advantage can be maintained while matching the lower NO value of the slower burning wedge chamber. This behavior is very significant since it shows that the judicious selection of spark timing and EGR rate can lead to both higher efficiency and lower NO emissions in the fast-burn chamber.

Kuroda et al. (11), in going from single ignition to dual ignition in the same combustion chamber and introducing varying amounts of EGR for oxides of nitrogen (NOx) control, also found that fast burning could achieve both higher efficiency and lower NOx. Likewise, Thring (13), going from one up to four spark plugs to increase burning rate in a given combustion chamber, found the dual improvement with faster burning. As an additional part of his studies, Thring used alternate design approaches to achieve the same burning rate, as indicated by the time in crank-angle degrees to go from burning 10% of the mixture to burning 90% of the mixture. Included among these approaches were different combinations of four spark plugs, the use of ordinary or extended electrode spark plugs, and the use of a shrouded intake valve to create fluid motions conductive to faster flame speeds and therefore faster burning rates.

An important finding was that engine efficiency and NOx emissions were not unique functions of the burning rate. While both of these parameters increased as the burning time was reduced, their magnitudes at a given burning time depended upon the approach taken to achieve that particular burning time. To modify slightly a former advertising slogan, "It's not how short you make it, but how you make it short that is important."

With regard to hydrocarbons, the data of Tuttle and Toepel (10) shown in Fig. 10 indicate no significant influence of burning rate on the hydrocarbon emissions index (grams of the HC per kilogram of fuel). The data do show, however, that operation at low EGR rates and retarded spark timing is an effective means to lower HC emissions, primarily due to the resulting higher exhaust temperatures demonstrated earlier with the engine simulation.

There are two factors associated with the formation of hydrocarbons. First, as thermal efficiency increases with faster burning, the exhaust temperature generally decreases. This leads to lower HC oxidation rates and therefore higher HC concentrations in the exhaust port. In fact, Mayo (12) has found an almost linear variation of HC concentration with burning time. For a given engine load, however, the higher efficiency for the faster burning means that less total mass flow is required through the engine, which may more than compensate for the higher HC concentration and lead to lower HC emissions expressed on a mass per unit time, or per vehicle mile traveled basis. These conflicting trends make it difficult to establish a general rule regarding the effect of burning rate on HC emissions. For example, Kuroda et al. (11) have found the HC emissions on a mass per unit time basis to be lower for fast burning at a given EGR rate, while Thring (13) has reported no change in HC emissions at low loads and higher HC emissions with increased burning at high loads.

As a sidelight, the data of Figs. 9 and 10 illustrate a dichotomy regarding engine calibration factors. That is, high efficiency considerations dictate that optimum timing be established with moderate EGR rates. Low HC emissions, on the other hand, favor low EGR rates and retarded timing, while low NO emissions favor high EGR rates and retarded timing. Managing these conflicting goals represents a formidable challenge in engine calibration. Adding to the difficulty of engine calibration is the need to provide good vehicle driveability by minimizing the cyclic variability of engine power.

SIMULATION STUDIES OF BURNING ENHANCEMENT APPROACHES - Lienesch (3) has used the engine simulation discussed earlier to examine the two approaches to faster burning rates. Starting with measurements of turbulence in the wedge-shaped chamber shown in Fig. 16 as a baseline condition, the turbulence level was

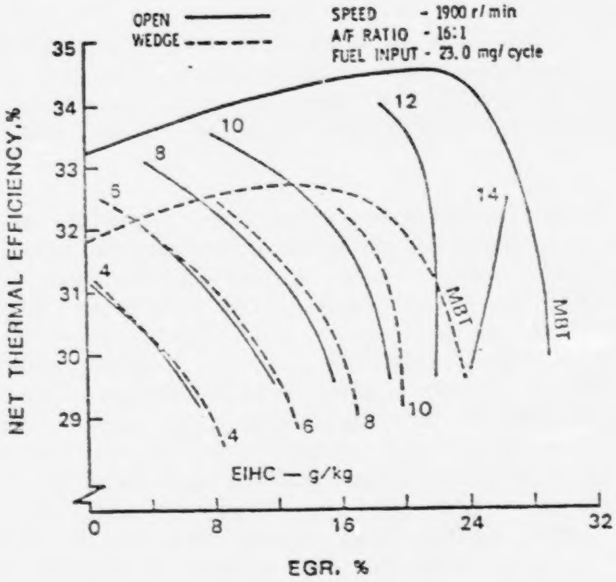
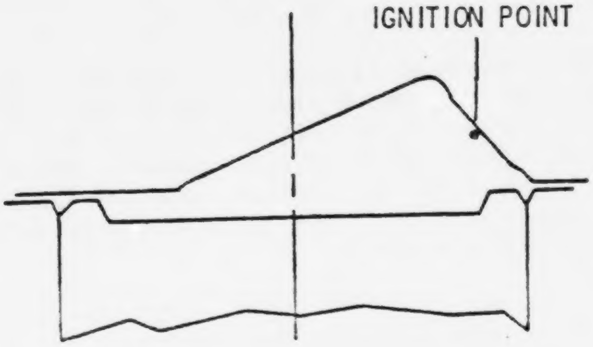
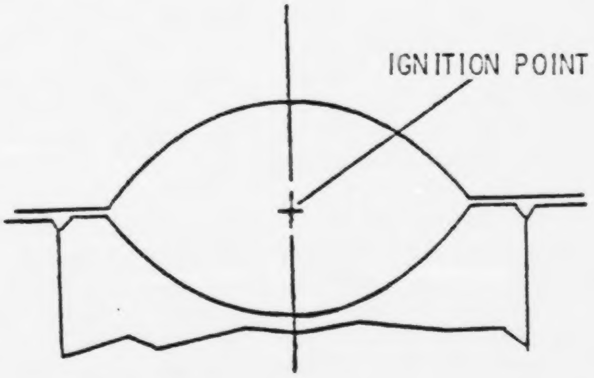


Fig. 10 - Efficiency - hydrocarbons tradeoff (10)


IGNITION POINT

WEDGE CHAMBER


IGNITION POINT

EXTREME OPEN CHAMBER

Fig. 16 - Combustion chambers of analytical study (3)

increased analytically by 50%, as might be accomplished experimentally (35) with a shrouded valve. Use of a correlation of burning velocity with turbulence developed experimentally by Groff and Matekunas (35) allowed the resulting engine performance to be predicted.

As an alternative to this fluid-motions approach, a second chamber was envisioned in which the cylinder head and piston crown both have concave spherical shapes and the ignition point is located in the center of the chamber. While such a shape is not practical to manufacture, its extreme openness represents an upper limit to the geometric approaches for increasing fuel burning rates.

The performance of the standard wedge, increased turbulence wedge, and extreme open chamber was analyzed for a light acceleration condition involving a stoichiometric air-fuel ratio, 10% nominal EGR and MBT timing. Results are given in Table 1 for near-equal NO exhaust concentrations, achieved by adding 1 to 3% of additional EGR to the fast-burn cases.

Starting with the standard wedge chamber and increasing the turbulence level resulted in a reduction of the combustion duration from 43 to 32 crank-angle degrees. However, in the case of the extreme open chamber, the duration was even shorter, namely 27 degrees. These variations resulted in a slight improvement in efficiency for the increased turbulence case and an even greater improvement in efficiency in going to the extreme open combustion chamber.

The reason for this higher efficiency is linked to the heat transfer. Because the high-temperature burned gases in the extreme open chamber do not contact the chamber wall during most of the combustion process, the heat losses in this chamber are significantly lower. In contrast, the wall contact of the flame in the wedge chamber plus the higher film coefficient (due to the higher pressure term in the Woschni (6) correlation) for the faster burn case caused greater heat-transfer losses. Had an additional increase in the film coefficient been made to account for the higher turbulence of this case, these heat losses would have been even greater. These heat-loss considerations account for the slightly higher exhaust gas temperature of the extreme open chamber in spite of its higher efficiency and more complete expansion.

Table I - Simulation Results*

Parameter	Standard Wedge (Case 1)	Increased Turbulence (Case 2)	Extreme Open (Case 3)	Units
Combustion Duration	43	32	27	°CA
Peak Burning Rate	13.2	18.0	25.3	mg/°CA
Peak Heat-Transfer Rate	3.8	4.3	3.3	J/°CA
Indicated Thermal Eff.	34.6	35.1	37.0	%
Exhaust Nitric Oxide	1530	1530	1520	ppm
Exhaust Temperature	1130	1115	1135	K

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* Retyped for clarity

While these results show the technique of increasing frontal areas to be more effective than that of increasing the turbulence level, generalizations should not be drawn. First of all, the heat-transfer model in the engine simulation is not sophisticated enough to account for details of chamber geometry and fluid motions. Furthermore, the heat-transfer correlation (6) may not be applicable for engine designs far removed from conventional practice. In addition, the ignition delay computation procedure in the engine simulation does not account for swirl effects, thereby underestimating the influence of swirl on the overall time of the combustion event. Finally, as mentioned before, the extreme open chamber design represents an upper-limit case which is impractical to manufacture for many reasons. Within these constraints, the study does indicate that there may be a limit to the optimum amount of turbulence, after which excessive heat losses cause a drop in efficiency.

Some evidence of this situation is indicated by the experimental data of Thring (13) discussed earlier. To review, the NOx and indicated specific fuel consumption were not a unique function of combustion duration. When the same combustion duration was obtained, in one case with increased swirl and in the other case with multiple spark plugs, the increased swirl led to greater heat losses, which produced lower NOx but lower indicated efficiency as well.

CONTEMPORARY ENGINE DESIGNS

The fast-burn approach to engine combustion is rapidly being adopted in new engine designs throughout the world. A small sample of some of these new designs is illustrated in Fig. 18 [and 19].

In figure 18, a cross-section of the General Motors 2.8 L V-6 engine designed by Chevrolet (39), shows the chamber to be somewhat open with a near-central spark plug location.

Another geometric approach to fast burn is shown in Fig. 19, where the original shallow cavity of a flat-topped piston in a wedge-shaped chamber was redistributed to provide an offset cavity. The original compression ratio was maintained. This offset cavity provides a large frontal area to the propagating flame while improving the fuel octane requirement by providing more effective cooling of the end gas. In experimental studies (17) with this piston, the attributes of fast burning were realized. This piston-cavity approach has been employed in the turbocharged versions of the Pontiac 4.9 L V-8 engine (40, 41).

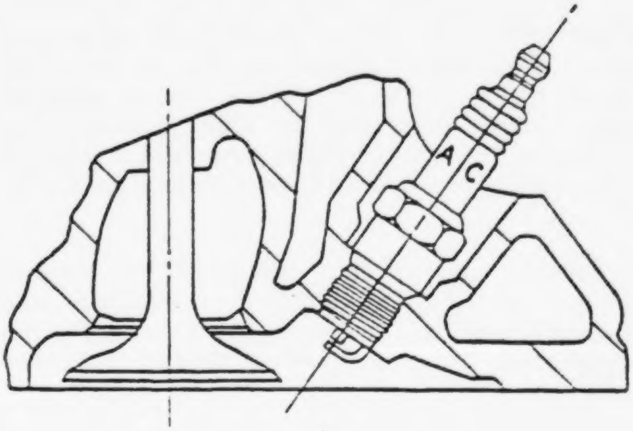

Fig. 18 - General Motors 2.8 L V-6 combustion chamber (39)

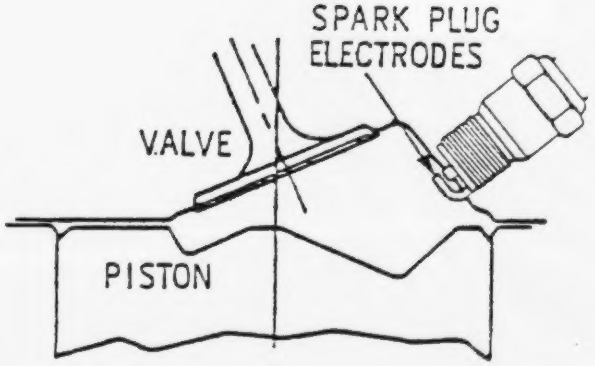
SPARK PLUG
ELECTRODES
VALVE
PISTON

Fig. 19 - Experimental modified wedge chamber (17)

SUMMARY

Fast burning in engines has been shown to have a number of attractive attributes. Among these advantages is an improved tradeoff between efficiency and NOx emissions and a greater tolerance to dilution, either with EGR or with excess air. Resulting from the combined effect of these two traits is the potential for simultaneously achieving higher efficiency and lower NOx emissions.

Fast burning also reduces the cyclic variation of engine power, which can improve vehicle driveability. Furthermore, the greater resistance to knock with faster burning can allow the fuel economy advantages associated with higher compression ratios to be realized.

A number of different combustion chamber design techniques exist for accomplishing fast burning. These techniques fall into the two categories of altering the combustion-chamber shape and affecting the fluid motions in the chamber. Combining these different techniques into an "optimum" combustion chamber design, while still recognizing all of the important constraints, offers a challenge as well as an opportunity for the engine designer.

Finally, the growing number of new engines throughout the world incorporating fast burning attests to the merits of this concept.

References*

1. J. C. G. Hempson, "The Automobile Engine, 1920-1950," Paper 760605, presented at SAE West Coast Meeting, San Francisco, August 1976.

3. J. H. Lienesch, "Engine Simulation Identifies Optimal Combustion Chamber Design." Presented at Seventeenth FISITA International Congress, Hamburg, West Germany, May 1980.

6. G. Woschni, "A Universally Applicable Equation for the Instantaneous Heat Transfer Coefficient in the Internal Combustion Engine." SAE Transactions, Vol. 76, 1967, pp. 3065-3083.

10. J. H. Tuttle and R. R. Toepel, "Increased Burning Rates Offer Improved Fuel Economy-NOx Emissions Trade-Offs in Spark Ignition Engines." Paper 790388, presented at SAE Automotive Engineering Congress, Detroit, February 1979.

11. H. Kuroda, J. Nakajima, K. Sugihara, Y. Takagi and S. Muranaka, "The Fast Burn with Heavy EGR, New Approach for Low NOx and Improved Fuel Economy." SAE Transactions, Vol. 87, 1978, pp. 1-15.

12. J. Mayo, "The Effect of Engine Design Parameters on Combustion Rate in Spark-Ignited Engines." SAE Transactions, Vol. 84, 1975, pp. 869-888.

13. R. H. Thring, "The Effect of Varying Combustion Rate in Spark Ignited Engines." Paper 70-387 [sic], presented at SAE Automotive Engineering Congress, Detroit, February 1979.

14. D. R. Lancaster, R. B. Krieger and J. H. Lienesch, "Measurement and Analysis of Pressure Data." SAE Transactions, Vol. 84, 1975, pp. 155-172.

15. R. V. Fisher and J. P. Macey, "Digital Data Acquistion with Emphasis on Measuring Pressure Synchronously with Crank Angle." Paper 750028, presented at SAE Automotive Engineering Congress, Detroit, February 1975.

16. M. B. Young and J. H. Lienesch, "An Engine Diagnostic Package (EDPAC)-Software for Analyzing Cylinder Pressure-Time Data." Paper 780967, presented at SAE International Fuels and Lubricants Meeting, Toronto, November 1978.

17. J. N. Mattavi, E. G. Groff, J. H. Lienesch, F. A. Matekunas and R. N. Noyes, "Engine Improvements Through Combustion Modeling." Proceedings of Symposium at General Motors Research Laboratories on Combustion Modeling in Reciprocating Engines, J. N. Mattavi and C. A. Amann, Editors, Plenum Press, New York-London, 1980, pp. 537-587.

18. A. A. Quader, "Effects of Spark Location and Combustion Duration on Nitric Oxide and Hydrocarbon Emissions." SAE Transactions, Vol. 82, 1973, pp. 617-627.

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* Only those references which were cited in the previous excerpts were included in this listing. The original reference numbers were used for this document.

34. D. R. Lancaster, "Effects of Engine Variables on Turbulence in a Spark Ignition Engine." SAE Transactions, Vol. 85, 1976, pp. 671-688.

35. E. G. Groff and F. A. Matekunas, "The Nature of Turbulent Flame Propagation in a Homogeneous Spark-Ignited Engine," Paper 800133, presented at SAE Automotive Engineering Congress, Detroit, February 1980.

39. D. A. Martens, "The General Motors 2.8 Liter 60° V-6 Engine Designed by Chevrolet." Paper 790697, presented at SAE Passenger Car Meeting, Dearborn, June 1979.

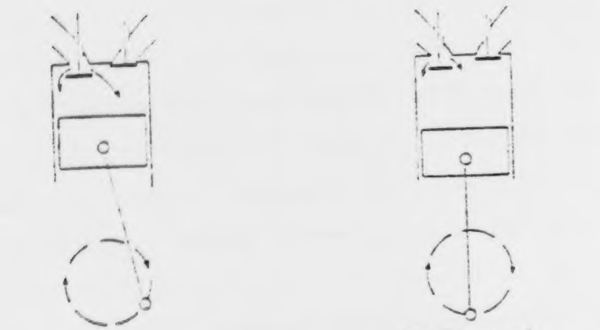
40. "Automotive Industries." October 1979, p. 87.

41. "Automotive Design and Development." May 1980, pp. 16-17.

C. In a SAE Paper (#800794) titled "Controlling Engine Load by Means of Late Intake-Valve Closing", General Motors described a technique of reducing an engine's pumping losses in order to improve thermal efficiency, with the accompanying benefit of considerably reduced NOx emissions. Pumping losses are defined as the power required to pump the fuel-air mixture into and out of the cylinder during the intake and exhaust strokes. Pumping losses were reduced by "delaying intake-valve closing (with respect to a conventional intake-valve closing) as a method of controlling the engine load without incurring the usual part-load throttling losses." The following excerpts more fully describe the concepts and the results.

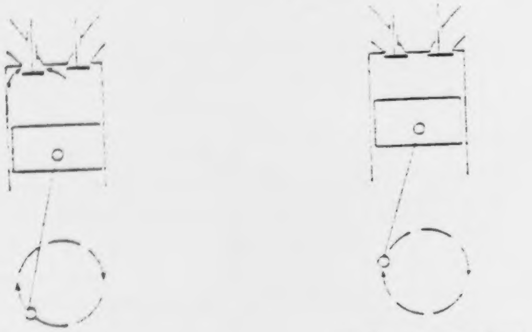
CONCEPT

> The late intake-valve-closing (LIVC) engine is an engine with the power output regulated by controlling the crankangle at which the intake valve closes. An LIVC engine operating at part load is depicted in Fig. 2. As in the case of a conventional engine, the intake valve opens just prior to and remains open throughout the intake stroke of the engine. However, the intake valve also remains open over a portion of the compression stroke while the piston pushes part of the cylinder charge back into the intake manifold. After the intake valve closes, the remainder of the compression stroke, as well as the expansion and exhaust strokes, are similar to those of a conventional engine.
>
> An idealized pressure-volume diagram for an LIVC engine is shown in Fig. 3. For comparison, an idealized pressure-volume diagram for a conventional engine is also shown. The pumping losses of the conventional engine operating at part load are substantial, as depicted by the shaded area in Fig. 3. In contrast, since the LIVC engine inducts fresh charge at near atmospheric pressure (unthrottled), the throttling losses are nearly eliminated for all load conditions. The trapped cylinder charge, and therefore power output, is determined by the effective cylinder volume at the time of the intake-valve closing V_{IVC} of Fig. 3. A mechanism that would vary the time the intake valve closes as a function of speed and desired load would allow the LIVC engine to achieve the same maximum power as that of an equal-displacement conventional engine, while providing lower part-load pumping losses.



a) Intake Stroke

b) Start of Compression Stroke



c) Compression Stroke (before Intake Valve Closes)

d) Compression Stroke (after Intake Valve Closes)

Fig. 2 - Depiction of LIVC operation

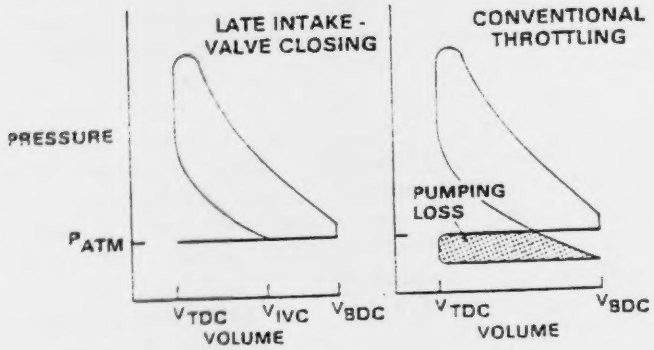


Fig. 3 - Pressure-volume diagrams

EXPERIMENTAL EQUIPMENT

Because of the exploratory nature of this investigation, a variable valve-timing mechanism was not necessary. Rather, modification of the test engine to LIVC operation was accomplished by replacing the production camshaft with a splined shaft. The splined camshaft allowed cams of different dwells at maximum lift to be installed such that the intake-valve closing could be incrementally varied. The timings of exhaust-valve opening and closing and of intake-valve opening were the same as those of the conventional engine. The intake-and exhaust-valve opening and closing crankangles for the various intake-valve dwells investigated are listed in Table 2. Valve lifts are shown in Fig. 5 for both the conventional engine and an engine with the intake-valve closing delayed 80 degrees of crankshaft rotation. An intake-valve dwell of 0°CA corresponds to the conventional engine.

Table 2-Valve Timing

Intake-Valve	Exhaust Valve		Intake Valve	
Dwell (°CA)	Open	Close	Open	Close
0 (conventional)	88°BBDC	52°ATDC	38°BTDC	82°ABDC
60	88°BBDC	52°ATDC	38°BTDC	142°ABDC
80	88°BBDC	52°ATDC	38°BTDC	162°ABDC
96	88°BBDC	52°ATDC	38°BTDC	178°ABDC

RESULTS

All specific test data reported herein are based on integrated pressure cards. "Indicated" values represent power developed within the cylinder during the compression-expansion portion of the engine cycle, and "pumping" values represent the negative power required for the exhaust and intake strokes. The difference between these two powers is termed the "net" power.

ENGINE LOAD CONTROL - The power output of the LIVC engine is controlled by the effective cylinder volume* at the time of the intake-valve closing. Increasing the dwell of the intake valve at its maximum lift decreases the cylinder volume at the intake-valve closing, thus decreasing the amount of fresh charge trapped in the cylinder.

FUEL CONSUMPTION - The fuel-consumption characteristics of the LIVC engine relative to those of the conventional engine were analyzed as the additive result of changes in both the indicated and pumping portions of the engine

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* The term "effective cylinder volume" is used to denote the cylinder volume at which the intake valve is effectively closed.

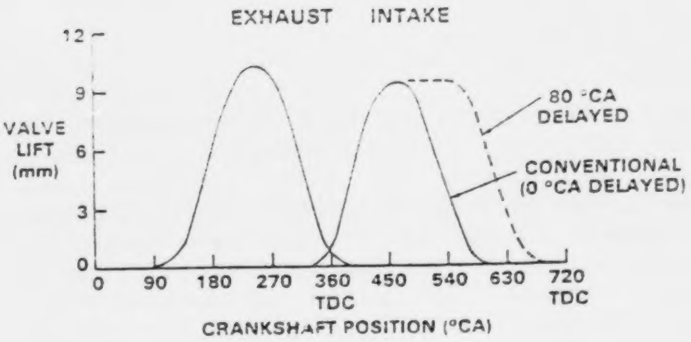

Fig. 5 - Valve-lift diagram

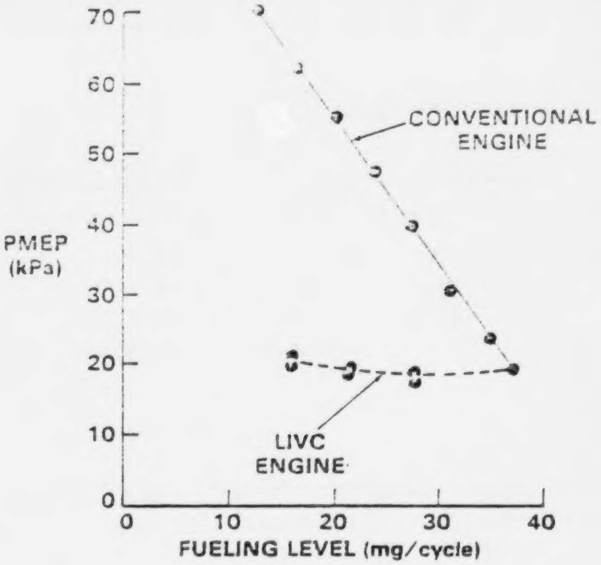

Fig. 9 - PMEP versus fueling level

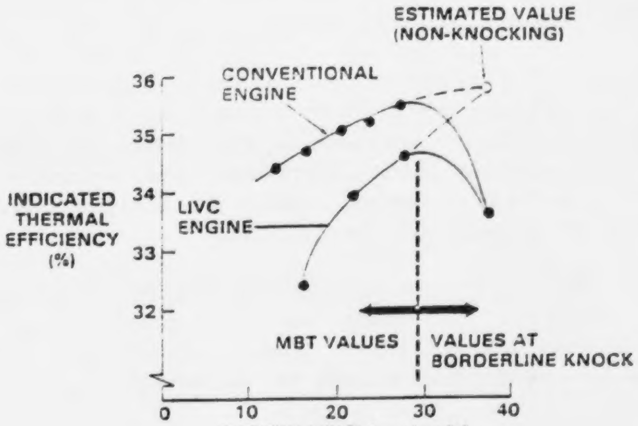

Fig. 10 - Indicated thermal efficiency versus fueling level

cycle. The change in the pumping portion of the cycle is presented first. Because the LIVC engine inducts fresh charge at near atmospheric pressure, the pumping losses of the engine are expected to be much lower than those of the conventional engine. Values of pumping mean effective pressure (PMEP) for both the LIVC and conventional engines are plotted against fueling level in Fig. 9. As the fueling level of the conventional engine is decreased from the maximum value, the PMEP of the engine continually increases. The values of PMEP shown in Fig. 9 for the LIVC engine are essentially the same as those of the conventional engine operating at WOT. Thus the LIVC concept of load control can limit engine "breathing" without incurring the large throttling losses associated with a conventional engine operating at part load.

Indicated thermal efficiency is plotted versus fueling level in Fig. 10 for both the LIVC and the conventional engines. With the exception of the highest values of fueling level in Fig. 10, the values of indicated thermal efficiency are not MBT spark timing. At the highest values of fueling level, MBT timing could not be attained due to knocking of the engine on the 97 RON fuel. Under knocking conditions, the indicated thermal efficiency in Fig. 10 is that corresponding to borderline knock. Estimated values of indicated thermal efficiency for non-knocking operation are represented by the dashed line. For non-knocking operation, the rate of decrease in indicated thermal efficiency with decreasing fueling level (load) is significantly greater for the LIVC engine. The cause of the larger decrease in indicated thermal efficiency for the LIVC engine will be addressed later.

Even though the LIVC engine is at a disadvantage when indicated thermal efficiencies are compared, the lower pumping losses of this engine result in its having an advantage when net thermal efficiencies are compared. Net thermal efficiency is based on the indicated output power less the pumping losses and, consequently, gives credit for the lower PMEP of the LIVC engine. Fig. 11 is a plot of net thermal efficiency versus fueling level and shows the improvement in net thermal efficiency of the LIVC engine over the conventional engine to increase with decreasing fueling level.

The data of Fig. 11 are replotted in Fig. 12 as net specific fuel consumption (NSFC) versus net mean effective pressure (NMEP). Use of net output (indicated less pumping work) allows the fuel economy of the LIVC and the conventional engines to be compared at equal engine load, where equal engine load refers to equal NMEP. If the engine friction were unchanged between a conventional engine and one modified for LIVC operation, then

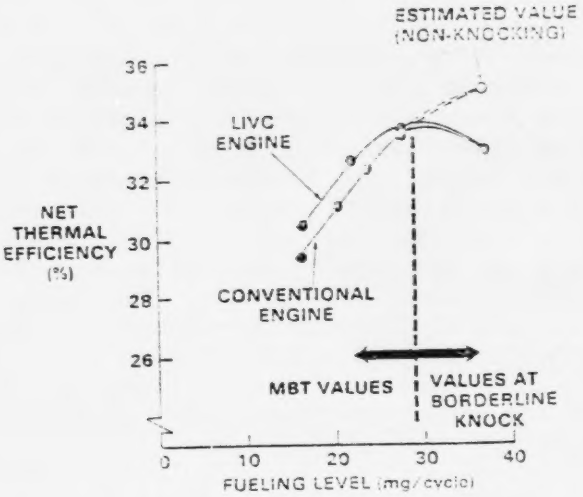

Fig. 11 - Net thermal efficiency versus fueling level

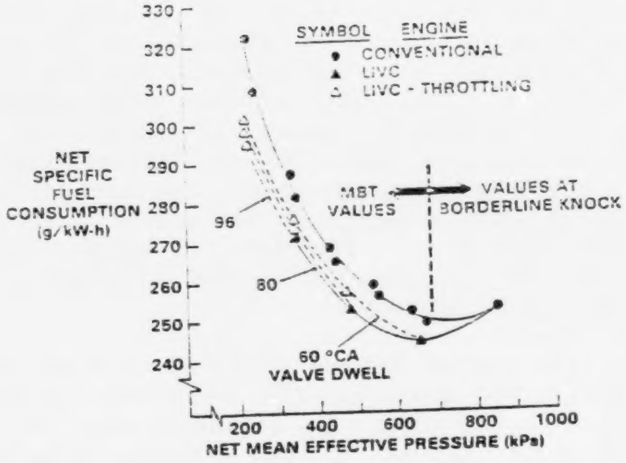

Fig. 12 - Specific fuel consumption

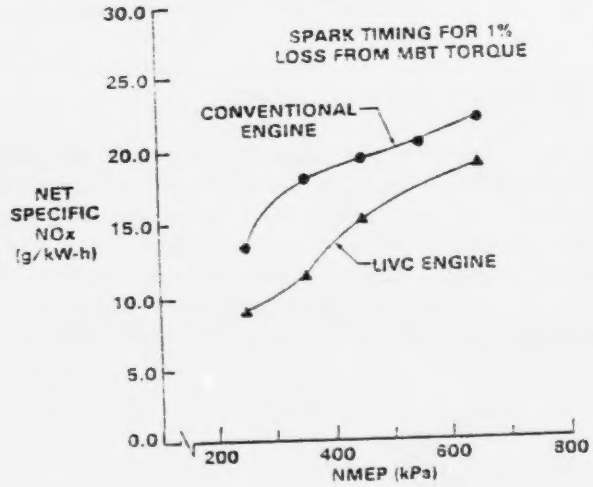

Fig. 15 - Specific NOx emissions

the comparison would also be valid at equal brake load. As mentioned earlier, because delayed intake-valve closing is limited to about 96°CA and because this amount of delay does not provide a range of load control sufficient for vehicle operation, LIVC must be combined with conventional throttling. Consequently, also included in Fig. 12 are data for which combinations of delayed intake-valve closing and conventional throttling were used to regulate engine load. These data are indicated by the dashed lines in Fig. 12, which connect data having a common value of intake-valve dwell The data indicate the fuel consumption when throttling is used to decrease the load further from that achieved by unthrottled LIVC operation.

In comparison to the conventional engine, both the throttled and the unthrottled LIVC engines exhibit improved fuel-consumption characteristics at part load. Comparing data for engine operation with combined LIVC and throttling to data for unthrottled LIVC operation shows the LIVC-plus-throttling method of load control has a higher NSFC than the unthrottled LIVC method. These results indicate that unthrottled LIVC should be used to control engine load for loads which can be regulated by intake-valve dwells of up to about 96°CA. For lighter engine loads, which cannot be achieved by unthrottled LIVC operation, a combination of 96°CA of intake-valve dwell plus conventional throttling exhibits the lowest fuel consumption.

EXHAUST EMISSIONS - Specific emissions of NOx are shown in Fig. 15 for both the conventional and the LIVC engines. These emissions are based on net output power. Because NOx emissions are extremely sensitive to spark timing near the MBT timing and because MBT spark timing itself is not always well defined, emissions are not compared at MBT power. Rather, emissions are compared at a spark timing which resulted in a 1% loss in engine torque from the MBT output. Emissions are not shown at the zero-dwell power (WOT power for the conventional engine) because knocking prevented the estimation of the MBT value of the engine torque.

At equal NMEP, the NOx emissions of the conventional engine can be seen in Fig. 15 to be considerably higher than those of the LIVC engine. At mid-load, the NOx emissions of the the LIVC engine are about 24% lower than those of the conventional engine. The higher NOx emissions of the conventional engine are attributable to its higher peak cylinder pressures and, as calculations showed, its higher peak cylinder-gas temperatures. The lower pumping losses of the LIVC engine allow the engine to have a substantially lower peak pressure while producing the same part-load NMEP as the conventional engine. The measured cylinder-gas pressures were input to a heat-release analysis [10] which computes the associated peak cylinder-gas temperature. At mid-load, the peak cylinder-gas temperature of the conventional engine is higher than that of the LIVC engine by 70 K.

Specific emissions of unburned hydrocarbons (HC) are plotted in Fig. 18. Again, the emissions measurements correspond to a spark timing which resulted in a 1% loss in torque from the MBT output. The HC emissions from the conventional engine and from the LIVC engine are not too different, particularly at the lower engine loading. Because exhaust-gas temperature will affect HC cleanup in a vehicular exhaust system, the measured exhaust temperatures are compared ... Since the temperatures are similar for the two engines, post-cylinder HC clean-up should be no more difficult for the LIVC engine than it is for the conventional engine.

CONCLUSIONS

1. Load Control - Delayed closing of the intake valve is limited to about 96 degrees of crankshaft rotation because greater delays cause large deterioration in indicated thermal efficiency. This amount of delay does not provide a sufficient range of load control for vehicular application. Consequently, the LIVC concept would have to be combined with a variable-density throttle control.

2. Fuel Economy -

   a. The LIVC concept of load control can limit engine power output without incurring the large throttling losses associated with a conventional engine operating at part load.

   b. In comparison to the efficiency of the conventional engine with its fixed compression ratio, the indicated thermal efficiency of the LIVC engine at part load is lower, and it decreases more rapidly with decreasing load. The lower indicated thermal efficiency of the LIVC engine at part load results from a lower effective compression ratio and a longer combustion duration.

   c. Although the indicated thermal efficiency of the LIVC engine is lower, the lower pumping losses result in the LIVC engine's having up to a 6.5% lower net specific fuel consumption than the conventional engine at the same light-load operation.

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[10] R.B. Krieger and G.L. Borman, "The Computation of Apparent Heat Release for Internal Combustion Engines," ASME Paper 66-WA/DGP4, 1966.

d. Conversion of a conventional engine to LIVC operation requires the addition of a control mechanism. Consequently, the fuel savings offered by the LIVC concept must be diminished by the losses inherent in any such control device.

e. The current trend toward lower vehicular power/weight ratios diminishes the fuel-economy benefit of the LIVC concept.

3. Exhaust Emissions -

a. At spark timings yielding a 1% loss in torque from the MBT values, the NOx emissions of the LIVC engine are considerably lower than those of the conventional engine. At mid-load, the reduction is about 24%.

b. HC emissions of the LIVC engine are similar to those of the conventional engine.

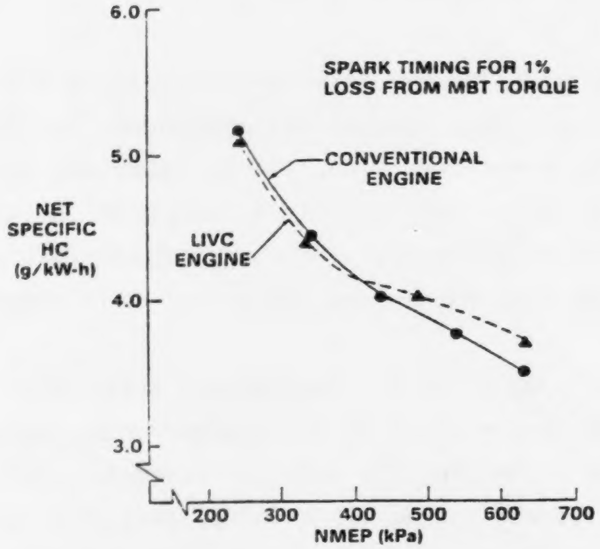

Fig. 18 - Specific hydrocarbon emissions

V. B. Ford

1. Ford Statements Concerning the Relationship between Emissions and Fuel Economy

A. High Altitude Emission Standards

Ford states that they believe that the implementation of the 1984 high altitude requirements will reduce their fleet average fuel economy by 2% to 7%. Ford states that this loss would result from their replacing fuel efficient configurations by less efficient ones. Ford claims, "The 1984 and Subsequent Model Years High Altitude Control Requirements could regulate out of existence some of the most fuel-efficient vehicle configurations because of their inability to simultaneously meet stringent high altitude standards and yield acceptable performance."* However, Ford did not provide any data to back up this claim.

B. Effects of Reducing the NOx Standard to 0.4 g/mi

Ford states, "Further reducing NOx emission levels below 1.0 g/mi could, in some cases, without further design and development of high EGR tolerance engines, cause power reduction, tip-in stumbles, lean sags and surging. These conditions can usually be minimized by reducing EGR rates and richer air-fuel mixtures. However, rich air-fuel operation is inconsistent with high fuel economy and low HC and CO objectives."*

Ford further stated that their "California cars will suffer an additional 8% loss in fuel economy in 1983 [relative to their 1981 model year counterparts] when the 0.4 NOx emission standard goes into effect (assuming this NOx standard can be met at all); that will lower CAFE by 0.2 MPG. These losses will occur in spite of the fact that we will be using sophisticated and very expensive emission control systems —

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* "Ford Status Report," February 1981, Sections IIA6 and IIJ.

including three-way catalysts and complex electronics to control fuel metering, spark timing, and other important parameters of the engine -- to minimize what otherwise would be much larger fuel economy losses."*

While Ford provided no data to substantiate the above claims, they did submit a summary of computer engine mapping results comparing the fuel economy of vehicles which meet the research target (0.41 HC, 3.4 CO, 0.41 NOx) versus vehicles whose emissions are totally uncontrolled. The comparisons used engine maps of vehicles equipped with 2.3 liter and 5.0 liter engines. Ford's results indicated that the unconstrained 2.3 liter vehicles obtained between 11% and 21% better fuel economy than the controlled versions, and the unconstrained 5.0 liter version produced between 9% and 12% higher fuel economy than their controlled counterparts. Ford obtained between 25.9 mpg and 26.0 mpg combined fuel economy with their uncontrolled 2.3 liter vehicles, and 17.8 mpg with their uncontrolled 5.0 liter vehicles.** Unfortunately Ford did not provide any emissions data or specifics on those vehicles (e.g., type of transmission, test weight, axle ratio, whether turbocharged, whether closed-loop, and whether fuel injected or carbureted). Since the Ford report was submitted in September 1979, the EPA technical staff examined 1980 model year Ford vehicles which were used to generate the fuel economy label values used by Ford for their 1980 model year vehicles equipped with either 2.3 or 5.0 liter engines. We found that the 2.3 liter, 2 barrel, manual (both 4- and 5-speed) transmission, open-loop vehicles produced 28 MPG_c, and thus exceeded the "best fuel economy" version in Ford's study. Similarly, the 5.0 liter, 2 barrel or fuel injected, automatic (3- and 4-speed) transmissions, open or closed-loop vehicles (with the exception of the LTD, LTD Wagon, Marquis, and Marquis Wagon) all achieved at least 18 MPG_c.*** We, therefore, have doubts concerning the accuracy of Ford's computer engine mapping technique as an indicator of EPA test results.

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* Hearings before the Subcommittee on Energy and Power of the Committee on Interstate and Foreign Commerce of the House of Representatives, March 13 and 14, 1979.

** "Ford 0.4 NOx Research Objective Program," September 1979, pages 1-2.

*** EPA/DOE 1980 Gas Mileage Guide.

C. Effects of Alternate "Standards" on Fuel Economy

Ford has studied the effects on fuel economy of a proposed (by Ford) emission standard of 0.39 g/mi non-methane HC, 9.0 g/mi CO, and 1.5 g/mi NOx compared to the current standard of 0.41 g/mi HC, 3.4 g/mi CO, and 1.0 g/mi NOx. Ford states, "Based on a preliminary analysis, such a change starting in the 1983 model year could, conservatively, provide an average benefit of 0.5-0.7 mpg to the fuel economy of the Ford fleet."* Since the 1983 CAFE standard is 26.0 mpg, Ford apparently believes that their proposed emission standard will result in a fuel economy improvement of approximately 2% to 3%. Ford provided neither the test data nor the analysis method used to predict that fuel economy improvement.

D. General Comments By Ford

Ford, in the same report states, "It has not been possible for Ford to separate the fuel economy penalty attributable to emission controls from the overall improvement in fuel economy, but the penalty is believed to be significant."** Ford's statements contradict the computer simulations of Heywood, Higgins, Watts, and Tabaczynski which indicate that fuel economy can be improved while controlling emissions. For example simultaneously increasing the amount of EGR and advancing the spark timing could increase fuel economy without causing the NOx to significantly increase.*** The resulting increase in HC could probably be handled by the catalyst. See figures Ford-1 and Ford-2.

E. General Comments by EPA's Technical Staff

It is quite time consuming to generate test data to analyze since it is difficult to run more than one city (FTP) test per day on a given vehicle. Ford eliminates this problem by running either steady-state

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* "Ford Status Report," February 1981, Section IIF.
** Ibid., Section III B.
*** Heywood, et. al, "Development and Use of a Cycle Simulation to Predict SI Engine Efficiency and NOx Emissions," SAE Paper 790291, page 18.

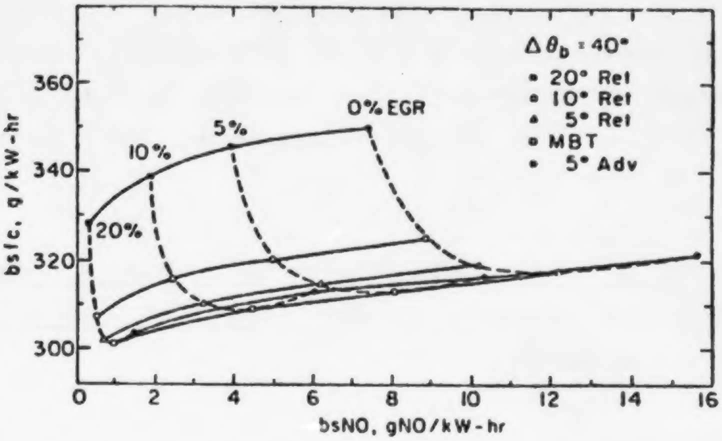

Figure Ford - 1*

- Lines of constant percent exhaust gas recycle, and constant timing relative to MBT, on a plot of brake specific fuel consumption versus brake specific nitric oxide emissions. Combustion duration 40°, equivalence ratio 1.0, 1400 rev/min, bmep 325 kPa

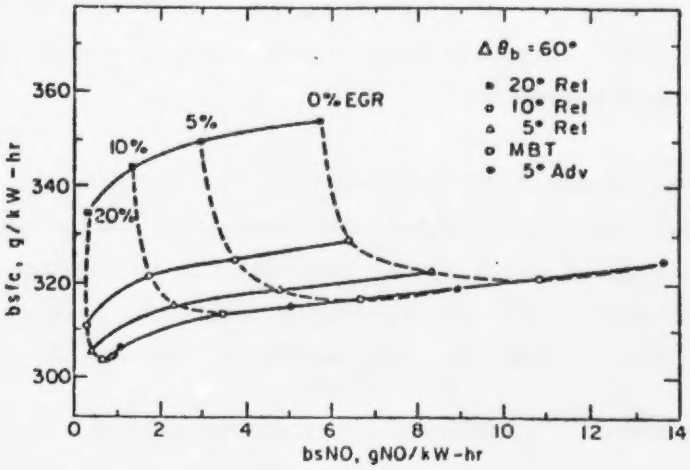

Figure Ford - 2

- Lines of constant percent exhaust gas recycle, and constant timing relative to MBT, on a plot of brake specific fuel consumption versus brake specific nitric oxide emissions. Combustion duration 60°, equivalence ratio 1.0, 1400 rev/min, bmep 325 kPa tests or by running what Ford calls a hot-CVS (which is a city test with the vehicle already warmed-up). Unfortunately, it is very difficult, if not impossible, to accurately predict both emissions and fuel economy results for the FTP cycle based only on steady-state or hot-CVS test results (as shown in appendix 1 of this report). Therefore, Ford's approach might not be correct for actual FTP results. Also, Ford makes a number of claims but without providing any data to document those claims.

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* Ibid., page 18.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy as Compared to 1981 Vehicles or Ford's Estimates.

A. New Engines

1. PROCO (PROgrammed COmbustion)

The PROCO engine is a direct injection, open chamber stratified charge engine. Fuel is injected into the combustion chamber during the compression stroke and ignited by dual spark plugs. Stratification is achieved by relatively late injection timing and the swirl of incoming air, resulting in a rich mixture in the vicinity of the spark plugs and a very lean mixture around the periphery of the combustion chamber.

Ford has tested PROCO engines with displacements of 7.5, 6.6, 5.8, 5.0, 3.3, and 2.5 liters.* Ford has found that, "Because the PROCO engine runs at overall lean air/fuel ratios and the fuel charge is concentrated in the center of the combustion chamber, thus reducing fuel contact with the cylinder head and walls, both HC and CO emissions are minimized. However, oxidation catalysts will still be required to meet the 0.41 g/mi hydrocarbons and 3.4 g/mi carbon monoxide emission standards. The NOx standard of 1.0 g/mi is also achievable due to this engine's ability to use large amounts of EGR."* Fortunately, the use of EGR should not lower fuel economy, as Ford explains, "The erroneous notion that EGR is inherently detrimental to fuel economy comes from the fact that EGR reduces the combustion speed. If the engine had the optimum combustion speed without EGR and measures are not taken to counteract the combustion speed reduction effect of EGR, then the fuel economy will indeed suffer from EGR. The combustion speed of the PROCO engine, however, is optimized for the 100% charge dilution condition with the aid of inlet swirl, squish, and dual ignition in order to take full advantage of the fuel economy potential inherent in charge dilution."**

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* "Ford Status Report," February 1981, Sections IIG & IIH,

Ford estimates that the PROCO engine, when calibrated to meet the 1981 statutory emissions standards, will produce a 20-25% fuel economy improvement over a carbureted, conventional gasoline engine of the same displacement which was also calibrated to the 1981 standards.**

According to Ford, the major problem in mass producing the PROCO engine "revolves around mass manufacturing of its precision fuel injection system which requires extremely tight tolerances. Pending continued successful development and resolution of manufacturing open issues, the PROCO may be available for production use by the mid-1980's."**

Ford states that, "As engine power-to-vehicle weight ratios are reduced, it may be necessary to turbocharge the smaller engine to restore the required performance level. In addition to meeting the required performance level, it may be necessary to turbocharge in order to meet the NOx emission control requirements. ...Testing to date indicates that turbocharging PROCO, with its inherently fast combustion, will require modifications to the current technology PROCO combustion system."* In fact Ford says, "The advanced [i.e. turbocharged] PROCO is not expected to be available prior to 1990."**

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* Nickol, "Automotive Powertrains - Now and into the 1990's," SAE Paper 801340, October 1980, page 6.

** Scussel, et al, "The Ford PROCO Engine Update," SAE Paper 780699, August 1978, page 4.

In a recent interview with "Ward's Engine Update," Ford Chairman, Philip Caldwell indicated that the PROCO engine will not be going into production. Ford will, however, try to incorporate some of the technological know-how they developed while working on the PROCO on some other projects that will go into production.***

2. Stirling

The Stirling engine that Ford is investigating is a reciprocating, closed cycle, continuous external combustion engine with multi-fuel capabilities. Ford states that, "Using gasoline, the Stirling has been projected to be capable of achieving up to 40% better economy than conventional gasoline engines, although experimental vehicles have fallen far short of this goal."**** These projections, however, are not based on actual test data.

Ford's work on the Stirling engine had been done under Department of Energy Contract No. EC-77-C-02-4396. At the conclusion of Task

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* "Ford Status Report," February 1981, Section IIH.

** Nickol, "Automotive Powertrains - Now and into the 1990's", SAE Paper 801340, October 1980, page 10.

*** Ward's Engine Update," Volume 6, Number 24, December 15, 1980, pages 5 & 7.

****Nickol, "Automotive Powertrains - Now and into the 1990's," SAE Paper 801340, October 1980, pages 11-12.

I in September 1978, Ford officially notified the Federal government agencies and private firms that it intended to withdraw from active participation in the development of the Stirling engine as an automotive power plant.*

3. Gas Turbine

Ford is a subcontractor to AiResearch Manufacturing Company of Arizona on the current NASA/DOE Advanced Gas Turbine Powertrain System (Contract No. DEN 3-37). "Ford believes that the ceramic single shaft turbine has the best potential of any turbine for attaining low emissions, excellent fuel economy and reasonable manufacturing cost. The potential of meeting a 0.4 [g/mi] NOx standard is yet to be determined."*

Ford and AiResearch believe that a 3000 pound car powered by such a turbine could achieve a fuel economy of 42.8 MPG_c; however, a vehicle is not planned to be available for testing until July 1981 and no test data is currently available.** There was no speculation as to when this engine might be available in automobiles.

4. Diesel

Ford is currently developing Diesel engines; however, there is no indication of when they will be available for production. Until Ford's Diesel is ready for production, Ford will purchase Diesel engines from companies such as Bayerische Motoren Werk AG (BMW)*** and Toyo Kogyo (TK).****

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* "Ford Status Report," February 1981, Section IIH.

** Rackley, "Advanced Gas Turbine Powertrain System Development Project," presented at Automotive Technology Development Contractors Coordination Meeting - Dearborn, Michigan, November 1980.

*** "Ward's Engine Update," Volume 6, Number 24, December 15, 1980, page 5.

**** "Ward's Engine Update," Volume 6, Number 20, October 15, 1980, page 6.

Ford's Diesel research has not reached a point at which they can predict fuel economy and emission results. They are currently investigating turbocharging and both direct and indirect injection combustion chamber configurations.*

As part of a correlation program with Ford, EPA tested a front-wheel drive Escort equipped with a manual transmission and a TK Diesel engine. A total of two tests were performed at EPA and eight tests at Ford; the average results of those tests are shown below:

		FTP (g/mi)						
Lab	# of Tests	HC	CO	NOx	Part.	MPG_u	MPG_h	MPG_c
EPA	2	.241	.70	.74	.184	37.1	51.4	42.4
Ford	8	.213	.69	.74	.145	36.4	50.8	41.7

It should be pointed out that, at both test facilities, the NOx levels are below 1.0 g/mi and the total particulate levels are below 0.20 g/mi.** There has been some interest in the fuel economy of a Diesel at these emission levels. This vehicle was tested at an ETW of 2750 pounds with a dynamometer horsepower (VDHP) setting of 6.7 horsepower. Two similar 1981 model year Diesel vehicles with manual transmissions were identified. The following table allows a rough comparison of these three vehicles:

Vehicle	ETW	VDHP	MPG_u	MPG_h	MPG_c
Ford Correlation Diesel	2750	6.7	37.1	51.4	42.4
Chevette Diesel	2500	8.3	40.1	55.1	45.7
VW Dasher Diesel Wagon	2625	6.9	36.0	48.0	40.6

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* Nichol, "Automotive Powertrains - Now and Into the 1990's," SAE Paper 801230, October 1980, pages 8-9.

** Watson, "Ford - EPA 1981 Light Duty Vehicle Diesel Correlation", EPA Technical Report No. EPA-AA-EOD-81-3, May 1981.

B. Continuously Variable Transmission (CVT)

A truly continuously variable transmission is one which permits ratio variations completely independent of vehicle speed or engine output. Its major advantage is that it provides the flexibility to run an infinite number of drive ratios between fixed upper and lower limits. Ford says that the advantages of the CVT are:

1. Smooth vehicle acceleration without shift impulses.
2. Acceleration with the engine operating very close to its optimum power output, thereby improving performance.
3. Road load engine operation at peak efficiency consistent with acceptable driveability, thereby improving economy, due to CVT's ability to optimize its performance within this narrow range.*

Ford states that, "To date, however, some of the apparent benefits have been offset by high internal frictional losses. Much work remains, making the CVT an unlikely prospect for the mid-1980's."**

3. The Effect of Known Technology which Helps Quantify Single or Multiple Calibrations or Vehicle Description Changes.

A. Automatic Overdrive Transmission (AOD)

The AOD, which Ford began using in the 1980 model year, incorporates three fuel savings features. First, the overdrive gear (fourth gear) has a gear ratio of 0.67 to 1.0, thus allowing the engine to operate at a lower speed than it would with a similar automatic transmission which had a final gear ratio of only 1.0-to-1.0. Secondly, the torque converter clutch directs the flow of engine power to completely bypass the torque converter and to follow a direct mechanical path to the driveshaft, thus eliminating torque converter losses while the transmission is in fourth gear. Finally, the transmission uses a split torque path which allows a portion of the engine power to bypass the torque converter and follow a mechanical path to the drive shaft, thus eliminating some of the torque converter losses. While none of those three features is unique in the automotive industry, Ford claims that the combination of all three "is an industry 'first.' Only Ford Motor Company offers this feature."*

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* Nichol, "Automotive Powertrains - Now and Into the 1990's", SAE Paper 801230, October 1980, page 13.

** "Ford Status Report," February 1981, Section IIF.

Ford claims, without providing substantiating data, that the overdrive gear can increase highway fuel economy (MPG_h) by up to 6%, that the torque converter clutch can increase combined fuel economy (MPG_c) approximately 4%, and that the split torque principle can improve MPG_c approximately 7%.**

Ford pointed out that this system could be improved by incorporating an electronic control system such that a single microprocessor would control both engine and transmission functions. Ford states that, "Potential benefits from such a system could include improved fuel economy through implementation of a neutral idle control strategy and increased transmission shift scheduling flexibility permitting the best compromise of shift timing to attain optimum fuel economy, emissions and driveability."*** However, Ford did not indicate if they are studying this possible improvement.

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* Dabich, "Ford Motor Company Automatic Overdrive Transmission," SAE Paper 800004, February 1980.
** Nickol, "Automotive Powertrains - Now and into the 1990's," SAE Paper 801230, October 1980, pages 12-13.
*** Ibid.

B. Weight Reductions

Ford's Metallurgy Department has been investigating the potential for using high strength steels (HSS) in place of mild steel. Ford states that "the use of higher strength steels allows for reduced weight in components that are primarily used in energy absorbing applications. An example of this is the widespread use of HSS in sidedoor beams with large weight reduction over original mild steel versions. ...Although the total weight of steel in future vehicles is somewhat uncertain, it is possible to project that sheet steel stampings will make up about forty percent of future vehicle weights. The overall penetration of high strength steel among the sheet steels is now about 20% in Ford vehicles; the authors speculate that this penetration will reach 30 to 50% of the total automotive sheet steel by the end of the decade... We speculatively project the application of high strength sheet steels per vehicle to approach the 300 to 600 pound range by the end of the decade."* Ford believes that the use of high strength steels will be a key feature in "achieving very significant worldwide fuel savings."** Ford anticipates that the use of high strength steels to replace average strength steels will result in the savings of 100 pounds per vehicle by 1985 (See figure Ford-3).** See figure Ford-4 for overall weight reduction.

C. Reduction of Internal Friction within the Engine

Ford's Fuel and Lubricants Department analyzed motored engine friction data from a Ford 1.6 liter and a Datsun 2.0 liter engine. Ford found the frictional losses in the Ford 1.6 liter engine were significantly higher than in the Datsun 2.0 liter engine. Ford determined that this

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* Magee, et.al., "Automotive Sheet Steels for the 1980's," May 1980.

** Magee, et.al., "Factors Influencing Automotive Applications of High Strength Steels," August 1979.

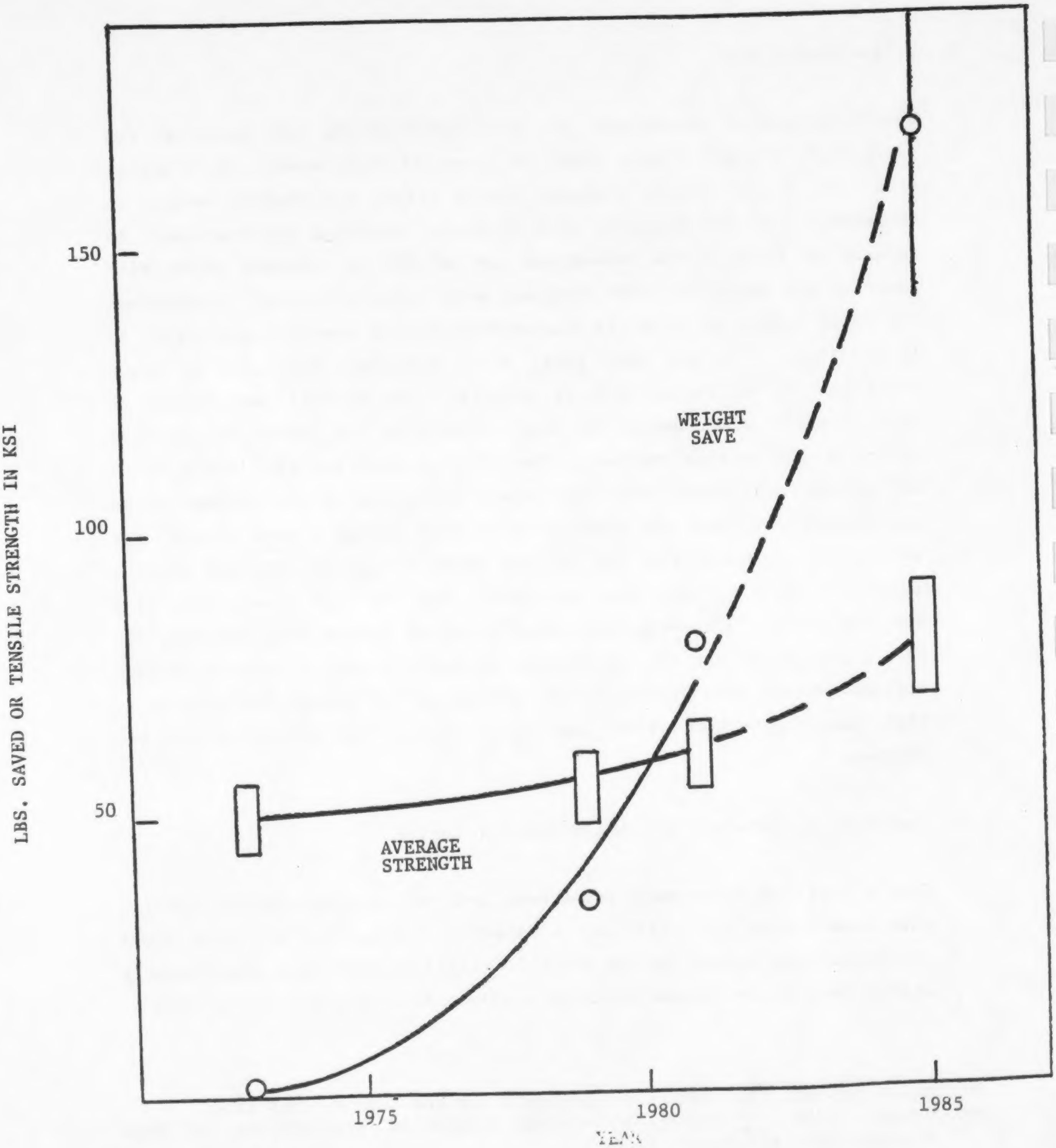

Figure Ford - 3*

Trends in strength level of HSS used in automobiles and the increased weight reduction

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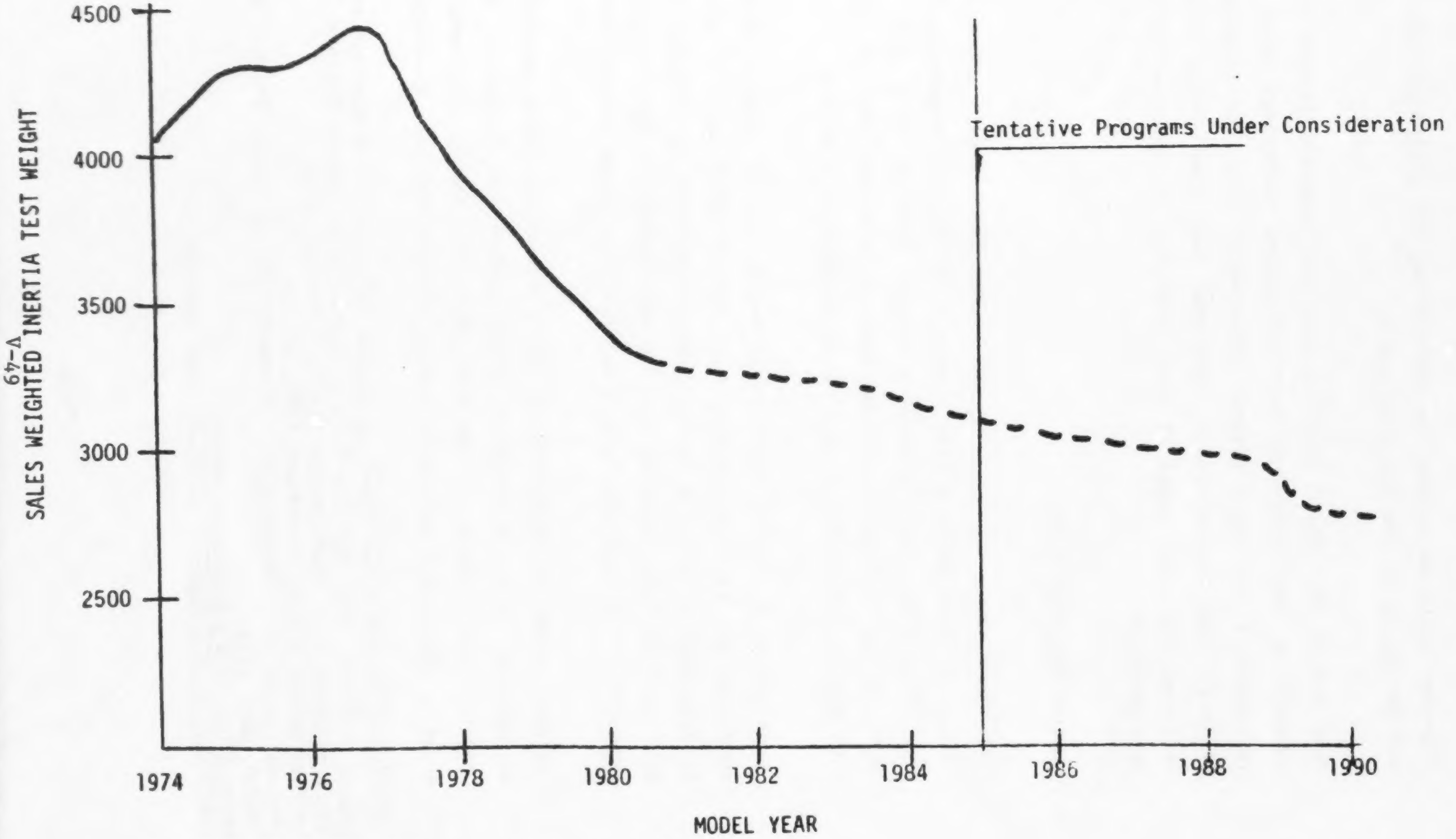
* Ibid.

Figure Ford - 4*

SALES WEIGHTED AVERAGE INERTIA TEST WEIGHT FOR FORD BY MODEL YEAR

PASSENGER CARS



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* "Ford Status Report," February 1981, Section IIF.

friction could be reduced by redesigning the piston/cylinder interface and by the use of low friction oils.*

Ford states that their "studies show that reduced friction engines incorporating fast burn/lean burn combustion technology offer potential for about a 12% fuel economy improvement over the original engine. Although some technological, cost and lead time issues remain to be resolved, increased usage of this technology is expected throughout the mid-1980's.**

D. Reducing Parasitic Losses

Ford found that, by replacing the conventional V-belt arrangement on a 1978, 5.0 liter Mustang with a serpentine drive arrangement, "increased belt flexibility and improved traction resulted in a more efficient drive system with potential increase of 0.04 mpg."*** An increase of 0.04 mpg on that model amounts to an increase of 0.2%.****

"Fans which deactivate when satisfactory engine cooling exists offer potential for improved on-road fuel economy which may, to some degree, be reflected on the EPA test. Electro-mechanically clutched fans have been used on Ford vehicles such as the Fiesta and Escort/Lynx and are expected to see more wide spread applications in the future."*****

Variable speed and two-speed accessory drives are being studied for use on vehicles with low power-to-weight ratios and relatively heavy accessory loads. These systems will drive air pumps, alternators, power steering pumps, and air conditioners. For the variable speed system,

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*Willermet, "Lubrication Modes and Engine Friction - A Comparison of Motored Engine Friction Data for the 1.6L Ford and 2.0L Datsun Engines," January 1981, attachment to "Ford Status Report," February 1981.

**"Ford Status Report," February 1981, Section IIF.

***Cassidy, et.al., "Serpentine - Extended Life Accessory Drive," SAE Paper 790699, June 1979.

****EPA/DOE 1978 Gas Mileage Guide.

*****"Ford Status Report," February 1981, Section IIF.

"[k]ey problem areas relate to durability, packaging and optimization of accessory performance." For the two-speed system, "ultimate usage is questionable on a cost/benefit basis."*

E. Supercharging

Ford claims that supercharging by way of a turbocharger can allow that engine to equal the performance of a naturally aspirated engine which is 50% larger than the turbocharged engine. Also, the turbocharged engine according to Ford, can provide approximately 9% better fuel economy than the larger naturally aspirated engine and with no significant impact on emissions.**

F. Decel/Idle Fuel Shut-Off System

This system shuts off the fuel, and hence the engine, when the engine is warm and would normally be idling. Ford claims, without submitting any supporting data, that this system provides a fuel economy improvement of 1% to 2% on vehicles equipped with either manual or automatic overdrive transmissions when tested on the FTP cycle excluding the cold start (Ford's HOT-CVS test cycle). Vehicles equipped with conventional automatic transmissions have fuel economy gains of less than 1%. Ford states these produce higher HC feedgas levels; however, there is no change in HC tailpipe levels. The problems with this system, according to Ford, are:

1. Without a speed signal, the system gives poor driveability and potential stalls.
2. The system incurs substantial cost penalties for additional hardware (e.g., sensors, solenoids, etc.).*** However, some

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*"Ford Status Report," February 1981, Section IIF.

**Nickol, "Automotive Powertrains - Now and into the 1990's," SAE Paper 801340, October 1980, page 5.

***"Ford Status Report," February 1981, Section IIA3f.

of that hardware would already be present if the vehicles were equipped with a closed-loop system.

Ford states that, "These problems are expected to be resolvable and production incorporation is being studied or actively pursued for several engines."*

G. Multipoint Electronic Fuel Injection

Ford currently (1981 model year) uses central fuel injection (CFI) on its fuel injected models. Ford is working to develop a multipoint electronic fuel injection (EFI) system for use on 4-cylinder engines. The multipoint EFI system with its four injectors has the potential for greater control of the fuel metering than does the CFI with only its two injectors.** If this potential is realized, the multipoint EFI could result in an improvement in both emissions and fuel economy.

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* Ibid., Section IIF.
**Ibid., Section IIA3.

V. C. Chrysler

1. Chrysler's Statements Concerning the Relationship between Emissions and Fuel Economy

In CO waiver hearings, Chrysler said that fuel economy, on average, is degraded by about 2% for vehicles complying with the 3.4 g/mi CO standard, as compared to a 7.0 g/mi CO standard. According to Chrysler, the 7.0 standard would allow the use of richer A/F ratios during acceleration, to enhance the catalyst's NOx reduction capability. This allows the use of EGR and spark timing calibrations that are more optimum for fuel economy. The fuel economy benefit varies from one engine family to another depending on the degree to which EGR and spark timing calibrations have been compromised in order to meet the NOx standard. Chrysler indicated that, on average, fuel economy is expected to improve by 2%, but this was based on their judgment. They had not run back-to-back tests between vehicles calibrated for 3.4 and 7.0 g/mi CO standards.*

In a historical review on emission controls, Chrysler commented that with the introduction of catalysts,

> it became necessary to remove lead from gasoline. The antiknock level of unleaded fuel that could be accomplished with existing refining technology was and is substantially below that which existed with the lead antiknock compound present. As a result, lower compression ratio had to be used with resulting loss in fuel economy.**

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* Transcript of Proceedings, United States Environmental Protection Agency, In the Matter of: Public Hearing on Applications for Waiver of Carbon Monoxide Emission Standards for Certain Model Automobiles, Washington, D.C., October 24, 1980.

** Charles M. Heinen, Chrysler Corp., "We've Done the Job - What's It Worth," SAE Paper 801357, October 20-23, 1980, pages 9 & 11.

This paper made the case that lighter vehicles with electronic engine controls and changes in

> mixture preparation and distribution should result in exhaust emissions before any catalyst of 1.5 HC, 10 CO and 1.5 NOx based on vehicles already in existence. These systems will be on vehicles regardless of the emissions requirements because of their fuel economy benefits. Without a catalyst a moderate amount of lead would be permissible. The results, of course, would be a gain of not only fuel economy, but a reduction in the cost of fuel with all their attendant benefits.

The author admitted that the fuel economy loss is a highly controversial subject, but referred to a Detroit News Editorial, June 9, 1980, for order of magnitude figures that indicated that leaded regular fuel would cost 6-7% less than unleaded fuel and improve fuel economy 5-10%.**

Table Chrysler-1 below was included in the SAE Paper cited above. This information was taken by Chrysler from the Annual Report of the Administrator of the Environmental Protection Agency to the Congress of the United States, "The Cost of Clean Air and Clean Water," 96th Congress, First Session, Document No. 96-38, December, 1979.

Table Chrysler-1**

Year	Fuel Consumption Penalty*	Year	Fuel Consumption Penalty*
1968	343.64	1978	1587.17
1969	599.19	1979	1349.58
1970	1033.89	1980	1049.19
1971	1556.84	1981	849.61
1972	2346.72	1982	524.89
1973	3304.32	1983	366.24
1974	2954.63	1984	255.02
1975	2540.78	1985	151.95
1976	2077.18	1986	85.44
1977	1851.86		

* millions of 1977 dollars

** Charles M. Heinen, Chrysler Corp., "We've Done the Job - What's It Worth," SAE Paper 801357, October 20-23, 1980, pages 9 & 11.

In their "Oxides of Nitrogen Research Plan for Model Year 1979," Chrysler stated the following:

> Chrysler's fuel economy improvement plans are based on increasingly more stringent emission standards which eventually reached the level of .41/3.4/1.0. If the 0.4 NOx level should ever be achievable, and a standard promulgated at that level our efforts to improve fuel economy would suffer a severe setback.**

Chrysler did not provide test data to support their comments regarding the relationship between fuel economy and emissions.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy as Compared to 1981 Vehicles or Chrysler's Estimate

The "Progress Report on Chrysler's Efforts to Meet the Federal Emission Standards for HC, CO, and NOx in 1981 and Subsequent Model Years," dated February 1981, discussed seven development programs whose objectives were to improve vehicle fuel economy. These include:

1. Vehicle weight reduction.
2. Power-to-weight reduction.
3. Drive trains.
4. Accessory drives.
5. Engine efficiency.
6. Tires.
7. Lubricants.

** Chrysler Corporation, "Chrysler's Oxides of Nitrogen Research Plan, for Model Year 1979," March 14, 1979, page 7.

This section will discuss only the new technology being developed by Chrysler in the above projects.

Chrysler began development efforts on lock-up torque converters in January of 1973 and entered production for rear wheel drive vehicles in the 1978 model year. They began development of lock-up torque converters for front wheel drive vehicles in June of 1976. Chrysler stated, "at the present time, however, the use of lock-up on front wheel drive cars has been deferred due to unacceptable driveability at the current state of development."* Chrysler did not discuss the impact on emissions nor quantify the effect on fuel economy for this technology.

In their engine efficiency program, Chrysler's "engine mapping and controls optimization" project seems to be their most significant program to improve fuel economy and emissions.

This project's objective is "to develop both the hardware and software for electronic control of spark timing, fuel/air ratio, exhaust gas recirculation, etc., so that fuel economy is maximized while emissions constraints are met."**

> The project includes chassis dynamometer measurement and computer simulation of engine speed/load requirements during EPA Urban and Highway driving cycles. Key speed/load conditions are selected by analyzing resulting histograms. The engine configuration is then "mapped" (steady-state) on an engine dynamometer at the "key" conditions for emissions and fuel consumption. From these data, for any reasonable emissions constraint, key point operating conditions can be found which predict minimum fuel usage on a hot '74 EPA cycle. These operating conditions are then incorporated in a vehicle and evaluated on a chassis dynamometer.

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* Chrysler Corp.,"Progress Report on Chryslers Efforts to Meet the Federal Emissions Standards for HC, CO, and NOx in 1981 and Subsequent Model Years," February 1981, page F-3.

** Chrysler Corporation, "Oxides of Nitrogen Annual Report for Model Year 1980," December 23, 1980, page I-9.

Engine maps have been obtained, under a contract with the Department of Transportation (DOT), for several versions of both the 318 CID V8 and 225 CID slant 6 engines, as well as turbocharged 1.7 liter 4-cylinder engine. Strategies have been obtained for the base 318 CID and 225 CID engines. Vehicle tests of these strategies are reported in the section on Integrated Engine Controls. A strategy for the turbocharged 1.7 liter engine has also been prepared.

Preliminary tests on Car 198 (360 CID) have been made that demonstrate the potential capabilities of the system and optimization strategies. Tests with "optimized" strategies for spark advance and EGR were compared against the standard spark advance and EGR control system. The "optimum" strategies were tested by programming schedules into a microprocessor capable of controlling spark advance and EGR. The fuel/air ratio was maintained around stoichiometric by an oxygen sensor feedback Holley 2 bbl. carburetor with Holley electronics. A summary of these tests follows [table Chrysler-2]*.

Table Chrysler-2*

Car 198, 360 CID Engine
HOT '74 EPA TEST

Tests	Engine Out Emissions (gm/mi) HC	CO	NOx	Fuel Economy MPG	Comments
15	2.84	26.9	1.71	12.3	Baseline-Mech. spark adv. and prod. EGR
20C	3.94	21.2	2.71	14.5	Schedule to improve fuel economy
Avg. of 4 tests	2.48	18.6	2.26	14.2	Schedule to improve HC
Avg. of 2 tests	2.42	19.9	1.66	13.9	Schedule to improve NOx

Control strategies have also been run on 318 and 225 CID engines (Cars 373 and 535, respectively). These cars were modified to include three-way catalysts and feedback carburetor systems. Typical results for hot '74 EPA tests are as follows:

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* Chrysler Corporation, "Application For Waiver of the 1981-1982 Model Year Carbon Monoxide (CO) Standard of 3.4 Grams Per Vehicle Mile For Passenger Cars," July 3, 1979 at Vol. II, pages B5-54, B5-55, & B5-57.

Table Chrysler-2 (con't)

Car 373, 318 CID Engine
Hot '74 EPA Test

	Engine-Out			Tailpipe			
Strategy	HC	CO	NOx	HC	CO	NOx	Fuel Economy
As received	2.7	22.6	1.5	.3	4.6	1.4	15.5
Minimum Fuel	3.0	12.5	3.5	.2	2.3	2.0	18.4
Emissions Constrained	2.6	10.9	2.1	.2	1.7	1.3	17.1

Car 535, 225 CID Engine

Hot '74 EPA test

	Engine-Out			Tailpipe			
Strategy	HC	CO	NOx	HC	CO	NOx	Fuel Economy
As received	Not Available			.4	7.9	1.4	19.4
Minimum Fuel	3.3	13.4	4.0	.4	3.1	2.2	21.3
Emissions Constrained	3.3	13.3	3.0	.3	3.2	.7	20.8

These data have been processed to identify optimum control strategies for specific vehicles with 318, 225, and 1.7 liter engines. The strategies are currently being evaluated. The results were presented in Volume II of Reference 22 Sec. B-5, pp. 54-57 [see table Chrysler-2]. Since that time, initial cold start and warm-up tests have been conducted on car 535. Preliminary results are:

Table Chrysler-3

Car 535, 225 CID Engine
Cold '75 EPA Test

	Engine Out			Tailpipe			
Urban Strategy	HC	CO	NOx	HC	CO	NOx	Corrected Fuel Economy
Emissions	4.00	20.6	2.13	.34	3.29	.37	17.9

This car was built up with experimental induction and emission control systems and does not directly compare to the 0.4 NOx program cars. The significance of the results, then, is that we have established that the program cars are achieving fuel economy comparable to the optimum values predicted from analytic evaluation of comprehensive engine data.

It should be noted that, informally, the systematic methodology discussed here has already had an evolutionary effect on our test philosophies and is expected to have increasingly greater impact. Therefore, all of these activities will continue except for the DOT project which is limited by contract.*

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* Chrysler Corporation, "Oxides of Nitrogen Annual Research Report fcr Model Year 1979," October 25, 1979 pages 23-24.

In addition to emission control systems optimization in engine mapping, Chrysler's engine efficiency program also includes projects to study the fuel economy benefits of:

a) Deceleration fuel shut-off
b) Reduced engine friction
c) Combustion chamber designs
d) Intake manifold designs
e) Turbocharged engines

The deceleration fuel shut-off project will restrict fuel flow during closed throttle deceleration in an attempt to improve fuel economy. Chrysler is now evaluating the fuel economy and driveability implications of this feature, but did not discuss or provide data on emissions or fuel economy and did not indicate when this technology would be used in production.*

For the 1981 model year, Chrysler has introduced lower tension oil rings in order to reduce engine friction. Chrysler is also evaluating other friction reducing items for their 2.2 L engine but has not indicated which components will be evaluated. No emissions or fuel economy data were provided.

Fast burn combustion chambers are being evaluated to develop a design "which combines the best possible part load efficiencies and dilution tolerance with high specific power output and reasonable fuel octane requirement."* Swirl ports and squish-type chambers with reduced flame travel distance are among those being evaluated. Chrysler did not indicate when the results of this development would be used in production, but said that the work is primarily based on a 1981 2.2 L engine. Chrysler said that the 2.2 L engine's combustion chamber "has proven to be a very good one with the exception that W.O.T. output is limited by valve shrouding in the deep, compact chamber design."* Emissions and fuel economy data were not provided.

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* Chrysler Corp., "Progress Report on Chrysler's Efforts to Meet the Federal Emissions Standards for HC, CO, and NOx in 1981 and Subsequent Model Years", February, 1981, pages F-7 & F-8.

In order to improve the power output of the 2.2 L engine, Chrysler has redesigned the intake manifold by reducing branch lengths and providing less restrictive flow paths. "The result was a large gain in mid-range to top-end power. This was transformed into a low-to-mid-speed torque benefit through advancing the camshaft timing."* Chrysler plans to introduce the new intake manifold in the 1982 model year.

Chrysler evaluated the use of turbocharged engines of smaller displacement than the naturally aspirated engines which they would replace, to increase fuel economy without a loss in performance. Chrysler concluded that turbocharged small displacement engines would not be a cost effective method for improving fuel economy for high volume production. No data were provided.*

Chrysler's tire test program includes rolling resistance tests in an effort to improve fuel economy. Chrysler stated:

> The rolling resistance characteristics of our current production tires are evaluated through head-to-head coast-down tests against tires on competitive domestic and foreign vehicles.
>
> The rolling resistance characteristics of the tires to be released for production are optimized by selecting only the best for production. This has resulted in a five percent reduction in vehicle force required as reported to the EPA between the 1980 and 1981 model years. Through competition between tire suppliers, all eventually had tires that were of about equal rolling resistance and were acceptable from other release standards.*

Chrysler said that although tire rolling resistance has improved greatly from 1979 to the 1981 model years, they do not feel that there will be any rolling resistance improvement for the near future until major improvements are made in design or compounding. Chrysler did not discuss the emissions impact of their tire test program.

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* Chrysler Corp., "Progress Report on Chrysler's Efforts to Meet the Federal Emissions Standards for HC, CO, and NOx in 1981 and Subsequent Model Years," February, 1981, pages F-7 to F-10.

A "fuel efficient" lubricant test program included evaluations of engine lubricants and axle lubricants. Four engine oils were tested for fuel economy improvements. Of these four, "only one, Sun Code X892, showed significant (1.6-3.2%) fuel economy improvement potential in the 225 CID engine."* The Sun Code X892 oil is now available commercially as Sunoco "MPG PLUS" oil. Chrysler said that since this oil includes a friction modifier containing phosphorus, durability tests would be required to determine the effect on catalysts and oxygen sensors. Chrysler did not indicate when this oil or other fuel efficient oils might be used in production. No emissions data were provided from this testing.

Table Chrysler-4 lists fuel economy improvements associated with the use of an experimental 75W axle lubricant as compared to an 80W-90 rear axle lubricant. According to Chrysler "additional economy testing of other candidate oils will be limited due to the future decrease of sales volume of rear wheel drive vehicles. It is estimated that no fuel economy improvement potential exists in this area for the corporate front wheel drive vehicles; therefore, similar tests were not planned." Although a fuel economy improvement was shown on all four vehicles "the 75W oil was considered unacceptable due to differential bearing wear and ring and pinion gear scoring." The effect on emissions was not discussed.

Table Chrysler-4
Axle Lubricant Test Results

REFERENCE OIL: MS-5644, SAE 80W-90 FACTORY FILL
TEST OIL: O.S. 38623, SAE 75W
CONTAINS SOLUBLE FRICTION MODIFIER

Vehicle Type	EPA Composite Economy Effect*
1978 "F" Body (225)	2.0% Improvement
1978 "F" Body (318)	0.6% Improvement
1979 "F" Body (318)	1.2% Improvement
1979 "D" Body 100	1.1% Improvement

*Compared to factory-fill baseline.

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* Chrysler Corp., "Progress Report on Chryslers Efforts to Meet the Federal Emissions Standards for HC, CO, and NOx in 1981 and Subsequent Model Years," February, 1981, pages F-10 & F-11.

Chrysler evaluated the feasibility of utilizing an oxidation catalyst system to meet emission standards of 0.41 HC, 3.4 CO, 1.0 NOx on a vehicle with a 2.2 liter engine. Chrysler's data, listed in table Chrysler-5, shows a 2 mpg fuel economy loss for the oxidation catalyst system on the FTP.

Table Chrysler-5

	Tailpipe			Engine-Out			Fuel Economy	
	HC	CO	NOx	HC	CO	NOx	Urban	Hwy
	-----g/mi----			-----g/mi----			-----MPG-----	
82 Dual Bed (DB)	.25	2.1	.58	2.0	11	1.80	26.0	34.4
Ox Cat (OC)	.19	1.9	.83	2.2	30	0.80	24.0	33.6
$100\,\frac{(OC-DB)}{DB}$, %	-24%	-9.5%	+43%				-7.7%	-2.3%
Difference (OC-DB)	-.06	-.2	+.25				-2.0	-0.8

In order to comply with the 1.0 g/mi. NOx standard, Chrysler used high EGR rates and rich A/F ratios. Chrysler said that this type of calibration "leads to unstable or inconsistant combustion which can produce undesirable vehicle surge and unsatisfactory performance under certain operating conditions."* The 30 g/mi. engine-out CO level for the oxidation catalyst system as compared to the 11 g/mi. CO level for the dual bed system indicates that it is likely that the oxidation catalyst equipped vehicle was operating with richer A/F ratios than the dual bed equipped vehicle. This may explain the 2 mpg loss in fuel economy. Chrysler also implied that the spark timing and EGR calibrations also had an adverse impact on fuel economy, but did not provide their specifications.

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* Chrysler Corp., "Progress Report on Chrysler's Efforts to Meet the Federal Emissions Standards for HC, CO, and NOx in 1981 and Subsequent Model Years," February, 1981, pages A-1 & A-2.

Chrysler's open chamber Diesel project is intended to determine the feasibility of using the open chamber Diesel engine in passenger cars.

> Early tests indicated significant potential for improvement of the fuel economy/NOx relationship over that of a prechamber engine if fuel injection timing and rate profile could be precisely controlled. Electromechanical actuators were developed to provide this control.
>
> Single and multicylinder tests confirmed indications of a superior fuel economy/NOx relationship. Fuel economy benefits of 10 to 15% over an equivalent pre-chamber Diesel were observed, along with some evidence that NOx levels below 1 gm/mi might be achieved.
>
> However, two major problem areas were identified:
>
> - HC emissions are excessively high in those areas where NOx control is best.
>
> - Fuel control system reliability is not sufficient to maintain a productive test program.
>
> An intensive series of tests involving combustion chamber parameters as well as a variety of fuel system components has indicated some promise for solving these problems. It is not yet possible to say, however, that this concept will achieve the anticipated lower emission levels while retaining a substantial fuel economy advantage. Current development efforts are directed to the near term solution of these problems.*

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* Chrysler Corp., "Progress Report on Chrysler's Efforts to Meet the Federal Emissions Standards for HC, CO, and NOx in 1981 and Subsequent Model Years", February, 1981, page H-2.

V.D. Toyota

1. Toyota's Statements Concerning the Relationship Between Emissions and Fuel Economy

A. Toyota states that "strengthened emission standards affect not only fuel economy but also all of other factors such as driveability, performance, durability, cost, etc." Toyota has been complying with the increasingly stringent emission standards by trading off the above factors except fuel economy. Toyota states, "Fuel economy cannot be sacrificed because it shares a large factor in market competition." Accordingly, Toyota is "optimizing and upgrading emission control systems in order to maintain or improve economy, which results in increased cost of system."*

Toyota included graphs (which appear on the next page, figures Toyota-1 and Toyota-2) which indicate the effects of various NOx standards (from 2.0 to 0.4 g/mi) on both fuel economy and on costs. These graphs show that to go from a NOx standard of 1.5 g/mile to one of 0.4 g/mile would increase cost due to the need to employ a more sophisticated technology; however, the new technology would increase fuel economy by as much as 10 to 15%.** A 15% increase in fuel economy for a vehicle rated at 25 MPG would result in a savings of 260 gallons of fuel during the first 50,000 miles. (At a fuel cost of $1.55/gallon, the savings would be $403.) On the graph, the system designated "P-2" indicates carbureted vehicles equipped with oxidation catalyst systems; "P-8-2" and "P-8-3" indicate carbureted vehicles equipped with closed loop 3-way catalyst systems; and "P-7" and "P-11" indicate fuel injected vehicles with closed-loop, 3-way catalyst systems.***

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*"Toyota Status Report - Efforts to Meet the 1981 and Subsequent Model Year Light-Duty Vehicle Emission Standards and Other Statutory Requirements," page 70.

** IBID., page 71.

*** IBID., page ii.

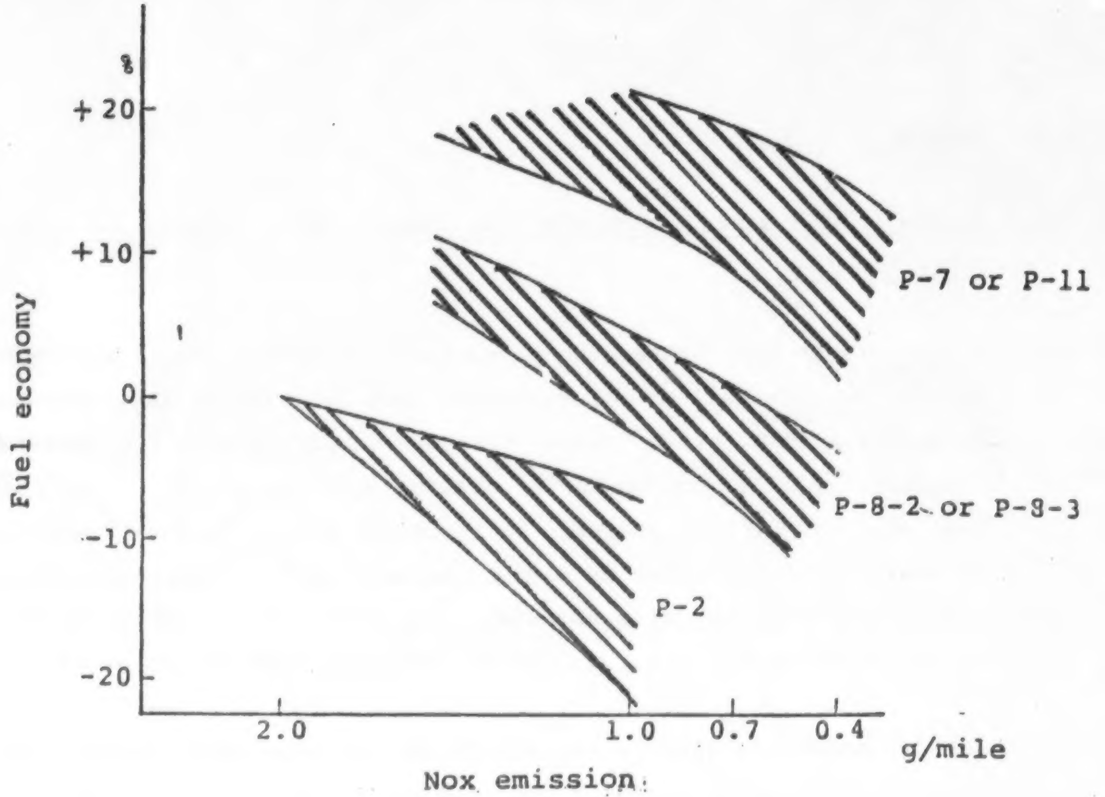

Figure Toyota - 1* NOx Emission VS. Fuel Economy

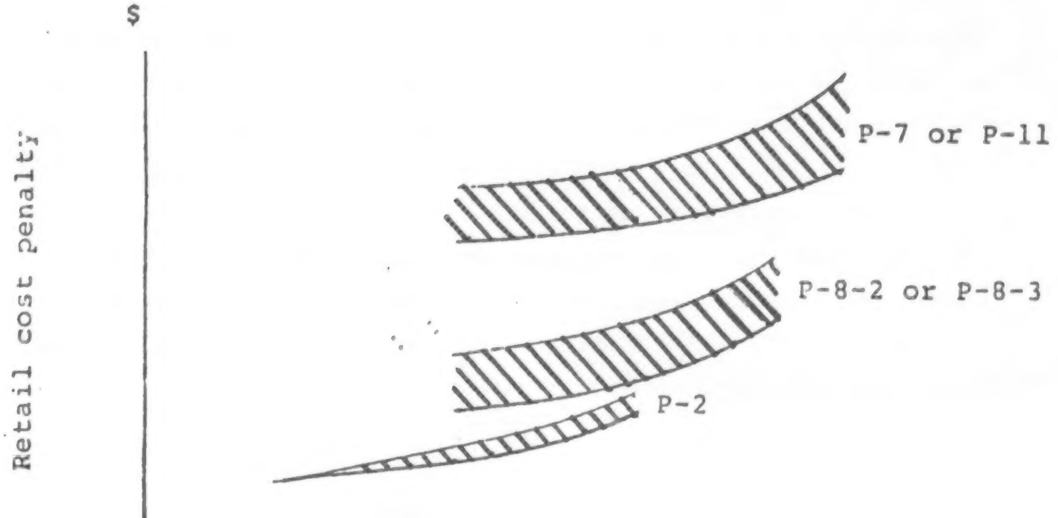

Figure Toyota - 2* NOx Emission VS. System Cost

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* Ibid., page 71.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy Compared to 1981 Vehicles or Toyota's Estimates.

A. Combustion Chamber Redesign

Toyota confirmed the general tendency for fuel economy to improve with increased EGR rate and advanced spark timing. When Toyota retarded the spark timing to decrease NOx, they found the fuel economy penalty was reduced by using a high turbulence type combustion chamber in place of a non-squish type chamber. The high turbulence type chamber, which used a "twist type piston", also reduced the HC emissions.*

Since the accompanying data were generated by using non-FTP test cycles, we cannot directly translate their results to probable changes in fuel economy on either EPA's urban or highway test cycles.

A similar calibration (high turbulence combustion chamber, higher compression ratio, extension of EGR tolerance) is being used for compliance with the Japanese emission standards. Toyota plans to investigate the feasibility of using a similar calibration to comply with the U. S. emission standards. The current problems are insufficient acceleration performance, higher NOx emissions, and insufficient fuel economy improvement.**

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* Matsumoto. et al, "The Effects of Combustion Chamber Design and Compression Ratio on Emissions, Fuel Economy and Octane Number Requirement," SAE Paper 770193, page 13.

** "Toyota Status Report - Efforts to Meet the 1981 and Subsequent Model Year Light-Duty Vehicle Emission Standards and Other Statutory Requirements," page 38.

Toyota provided emissions and fuel economy data generated with such a combustion chamber design change. Unfortunately, Toyota did not detail the changes. The following data were generated on a 3,000 lb. IW vehicle equipped with a five-speed manual transmission and a 2.4 liter, 4 cylinder engine* (the description of this vehicle is similar to that of the Toyota Celica):

	Compression Ratio	HC (gpm)	CO (gpm)	NOx (gpm)	Fuel Economy Gain (%)
Before Modification	8.4	0.100	1.65	0.55	(Baseline)
After Modification	9.0	0.104	1.65	0.56	5.5

B. Digitally Controlled EFI

Toyota introduced the digitally controlled EFI system into the Japanese market in August 1980. Use of this system, Toyota states, "results in the improvements in performance, driveability, fuel economy, and reliability" by controlling the "amount of fuel, ignition timing, and idle speed." Toyota did not submit any data to substantiate the claims. Toyota plans to phase this system into the U.S. market beginning in the 1983 model year.**

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* IBID., pages 64-65.
** IBID., page 37.

C. Single Point Injection (SPI)

Toyota says that they have been investigating the basic characteristics and "potentialities of performance and emission reduction of the SPI system for several years." Toyota says that they hope to improve the fuel metering accuracy over the current conventional carburetors or EFI systems by using a SPI system.

Toyota stated that, with the SPI system, they are currently experiencing the following problems:

1. "Unbalanced distribution of A/F mixture among the cylinders,
2. Large fluctuation of transient A/F ratio, and
3. Insufficient startability."

"After making a comparison among SPI systems and current carburetors or EFI systems," Toyota says they, will decide the policy of how to adopt the SPI systems to their engines.* SPI is, according to Toyota, more expensive and more fuel efficient than convential carburetors, but SPI is less expensive and less fuel efficient than EFI.**

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* IBID, pages 34-36.

** "Toyota NOx Research Program - 1979 Annual Report Period Plan," September 1979, page 15.

3. The Effect of Known Technology which Helps Quantify Single or Multiple Calibrations or Vehicle Description Changes

A. Vehicle Weight Reduction Programs

Toyota plans to reduce vehicle weight by "rational design, miniaturization, and material substitution." Some models will be lightened, and others will be replaced by new and lighter car lines during the 1980 through 1985 model years.*

The lightening of vehicles will improve fuel economy with no adverse effect on emissions.

B. Transmissions

1. Manual Transmission

To lower engine speed, Toyota adopted wide ratio transmissions and its fuel economy gain was about 2% for the 1981 models. Toyota plans to review the current gear ratios to gain additional fuel economy improvements for the 1983 models. Toyota did not state whether they anticipate any effects on emissions.

2. Automatic Transmission

To lower engine speed and eliminate slippage losses, Toyota plans, for the 1982 model year, to equip its Corolla and pickup truck with a four-speed automatic transmission with overdrive and its Celica Supra with an automatic transmission with a lockup torque converter. Toyota expects a fuel economy improvement of 2% to 4% with the automatic four-speed and an improvement of 1% to 2% with the lockup.

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* "Toyota Status Report - Efforts to Meet the 1981 and Subsequent Model Year Light-Duty Vehicle Emission Standards and Other Statutory Requirements," pages 57-58.

Toyota plans to improve the lockup torque converter by allowing the lockup function to operate in both second and third gears. They anticipate an additional 1% increase in fuel economy due to this improvement. Toyota plans to introduce this improved transmission on its 1983 model year cars.* Toyota did not state whether they anticipate any effects on emissions.

C. Toyota currently (1981 model year) has a 6 cylinder, 168 CID (gasoline) engine equipped with feedback EFI and 3-way catalyst (engine family number BTY2.8V5HB4). Of the 15 valid (non-void) FTP tests performed on the seven certification data vehicles in that family:

1. No HC emission level exceeded 0.226 g/mi (without DF),
2. No CO emission level exceeded 1.42 g/mi (without DF), and
3. No NOx emission level exceeded 0.32 g/mi (without DF).

Applying the applicable deterioration factors (HC = 1.385, CO= 1.385, and NOx = 1.275), we note that every FTP would meet the 0.41 HC, 3.4 CO, 0.41 NOx research target level. However, the durability vehicle line-crossed by generating a 50,000 mile calculated NOx value of 0.425 g/mi, which exceeds 0.41 g/mi.** Considering how close the durability vehicle came to being acceptable for use at the NOx research target, it is reasonable to assume that Toyota could achieve the research target using the technology which they currently employ on their 1981 model year Celica Supra, Cressida, and Cressida station wagon. Those models have EPA fuel economy values of:*

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*Ibid, page 60.

**EPA/MFR test data base as of February 10, 1981

Car Line	Transmission	MPG_u	MPG_h	MPG_c
Celica Supra	M5	21	29	24
Celica Supra	A4	22	29	25
Cressida	A4	22	29	25
Cressida Wagon	A4	22	29	25

If we compare these models' MPG_c with those of other 1981 model year cars, we see the fleet average MPG_c for all 3,000 lb IW cars is 24.85 mpg.** Thus, we conclude that Toyota is not suffering a fuel economy penalty on these models compared to the competition as a result of the low emission levels.

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* EPA/DOE 1981 Gas Mileage Guide

** Foster, Murrell, Loos, "Light Duty Automotive Fuel Economy ... Trends Through 1981,", SAE Paper 810386, February, 1981, page 16.

Section V. E. Nissan (Datsun)

1. Nissan Statements Concerning the Relationship between Emissions and Fuel Economy

This section summarizes Nissan's statements regarding the relationship between fuel economy and emissions.

In CO waiver hearing testimony*, Nissan said that they expected the fuel economy of their 1981 model year vehicles to improve about 15% to 25% over that of their 1979 model year Federal vehicles. Nissan also said that an air pump may be necessary to meet the 3.4 CO standard, but might not be necessary to meet a 7.0 CO standard. They felt that the increased parasitic horsepower due to the use of an air pump, could cause a one to two percent decrease in fuel economy.

In a status report,** dated, March 1981, Nissan said the following with respect to the relationship between emission standards and fuel economy.

> We have been proceeding with our research work on an oxidation catalyst system and on a 3-way catalyst system in an effort to develop a system that will meet the 0.4 g/mile NOx standard. The results that we have obtained with these two systems to date are shown in [table Nissan-1] and [table Nissan-2] and in [figure Nissan-1]. The specifications of the systems that produced these results are shown in [table Nissan-3] through [table Nissan-6].
>
> In order for the oxidation catalyst system to clear the 0.4 g/mile NOx standard, heavy EGR is required, but this has an adverse effect on combustion stability. Using a richer air-fuel ratio to improve combustion stability lowers fuel economy by more than 10%, in comparision with the fuel economy that can be obtained in clearing the 1.0 g/mile NOx standard.

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* Transcript of Proceedings, Environmental Protection Agency, "In the matter of; Public Hearing on Applications for Waiver of the 1981 and 1982 CO Emission Standard for Light Duty Vehicles," Washington, D.C., September 12, 1979, pages 91 and 92.

** "Research and Development Program Status Report for 1981 and Subsequent Emission Standards"; Nissan Motor Co., Ltd; March, 1981, pages 260 and 261.

Table Nissan - 1

Exhaust Emission and Fuel Economy

(Ox. Cat)

System	Veh. I.D.	IW lbs	Eng.	C/R	F/E mpg	CVS-CH gpm			Remarks
						HC	CO	NOx	
Oxi.Cat.	8D-968	2,750	Z20S	8.5	25.6	0.45	5.68	0.61	with catalyst
					25.4	0.39	3.03	0.65	
					25.9	0.43	3.84	0.68	
					25.4	0.40	3.91	0.70	
					25.6	0.40	3.86	0.71	
					26.3	0.42	3.54	0.74	
					25.8	0.48	2.62	0.81	
	YD-001	2,750	Z20S	8.5	23.9	0.31	4.67	0.35	
					23.6	3.79	28.8	0.42	w/o catalyst
					23.9	3.62	31.0	0.39	
					23.7	3.57	34.7	0.35	
					23.8	3.48	35.6	0.39	
	8D-972	2,750	Z20S	8.5	27.9	0.41	4.68	1.43	with catalyst
					27.5	0.32	4.00	1.57	
					27.5	0.34	3.49	1.67	

Table Nissan - 2

Exhaust Emission and Fuel Economy

(3-Way Cat.)

System	Veh. I.D.	IW lbs	Eng.	C/R	F/E mpg	CVS-CH gpm			Remarks
						HC	CO	NOx	
3 Way Cat	YD-020	2,750	Z20S ECC	8.5	25.8	0.19	2.26	0.23	with catalyst
					26.7	0.20	2.08	0.31	
					26.4	0.20	2.87	0.31	
					26.4	0.19	2.44	0.37	
					26.6	0.21	3.15	0.37	
					26.1	2.62	10.9	1.57	w/o catalyst
					26.9	2.04	10.5	1.60	
					26.4	2.04	11.5	1.62	
					26.6	2.03	10.7	1.53	
					26.6	2.15	11.3	1.65	

Figure Nissan - 1

RELATIONSHIP BETWEEN NOx AND FUEL ECONOMY IN OXIDATION CAT. SYSTEM AND THREE WAY CAT. SYSTEM

	OXI. CATALYST SYSTEM	3WAY CATALYST SYSTEM
ENGINE OUT NOx	●	▲
CATALYST OUT NOx	○	△

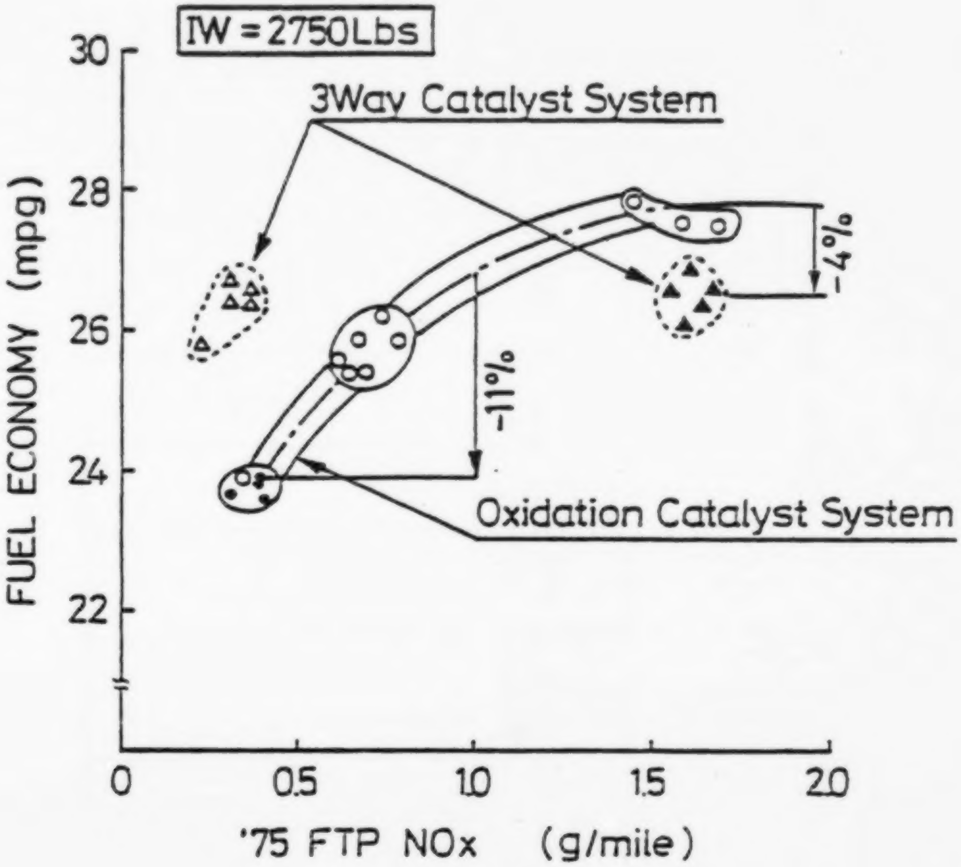

Table Nissan - 3

Vehicle Specifications

1. Vehicle ID. No.	8D-968
2. Vehicle model	Datsun 510
3. Model year	Experimental Vehicle
4. Inertia weight	2,750 lbs
5. Engine	L4, 191CID
6. Transmission	M4
7. Axle ratio	3.545
8. N/V ratio	53.3
9. Fuel metering system	Carburetter
10. Exh. emission control system	2 plug+EGR+EAI OX.CAT.
11. Catalyst	
(1) Type	Oxidation Catalyst
(2) Substrate construction	Monolith
(3) Size (inches)	Oval Width 6.68 in Height 3.18 in length 5.65 in
(4) Location	Under floor
12. EGR	
(1) Type	VVT
(2) EGR Rate	30% (2600 rpm x -300mmHg)

Table Nissan - 4

Vehicle Specifications

1. Vehicle ID. No.	8D-972
2. Vehicle model	Datsun 510
3. Model year	Experimental Vehicle
4. Inertia weight	2,750 lbs
5. Engine	L4, 191 CID
6. Transmission	M4
7. Axle ratio	3.545
8. N/V ratio	53.3
9. Fuel metering system	Carburetter
10. Exh. emission control system	2 plug+EGR+EAI+OX.CAT.
11. Catalyst	
(1) Type	Oxdation Catalyst
(2) Substrate construction	Monolith
(3) Size (inches)	Oval Width 6.68 in Height 3.18 i Length 5.65 in
(4) Location	Under floor
12. EGR	
(1) Type	VVT
(2) EGR Rate	20% (2600 rpm x -300 mmHg)

Table Nissan - 5

Vehicle Specifications

1. Vehicle ID. No.	YD-020
2. Vehicle model	Datsun 510
3. Model year	Experimental Vehicle
4. Inertia weight	2,750 lbs
5. Engine	L4, 191 CID
6. Transmission	M4
7. Axle ratio	3.545
8. N/V ratio	53.3
9. Fuel metering system	ECC
10. Exh. emission control system	ECC+EGR+TWC+CL
11. Catalyst	
(1) Type	3 Way Catalyst
(2) Substrate construction	Monolith
(3) Size (inches)	Oval Width 6.68 in Height 3.18 in Length 5.65 in
(4) Location	Under floor
12. EGR	
(1) Type	VVT
(2) EGR Rate	20% (2600rpm x -300mmHg)

Table Nissan - 6

Vehicle Specifications

1. Vehicle ID. No.	YD-001
2. Vehicle model	Datsun 510
3. Model year	Experimental Vehicle
4. Inertia weight	2,750 lbs
5. Engine	L4, 191 CID
6. Transmission	M4
7. Axle ratio	3.545
8. N/V ratio	53.3
9. Fuel metering system	Carburetter
10. Exh. emission control system	2 plug+EGR+EAI+OX.CAT.
11. Catalyst	
(1) Type	Oxdation Catalyst
(2) Substrate construction	Monolith
(3) Size (inches)	Oval Width 6.68 in Height 3.18 ir Length 5.65 in
(4) Location	Under floor
12. EGR	
(1) Type	VVT
(2) EGR Rate	25% (2600rpm x -300mmHg)

On the other hand, the 3-way catalyst system divides the work of reducing NOx emissions between EGR and the catalyst. In this system the NOx level that should be cleared by EGR is 1-1.5 g/mile, and thus the necessary EGR rate is not as heavy as in the oxidation catalyst system which uses only EGR to reduce NOx emissions. Consequently, the EGR rate in the 3-way catalyst system has no adverse effect on fuel economy.

As [figure Nissan-1] shows, however, the fuel economy of the 3-way catalyst system in clearing the 1.5 g/mile NOx standard is 4% worse than that afforded by the oxidation catalyst system. The reason is that since the air-fuel ratio in the 3-way catalyst system is controlled to the stoichiometric air-fuel ratio, a reduction in fuel consumption cannot be obtained by making the mixture leaner.

Irrespective of the durability, driveability and cost of each system, the fuel economy afforded by the 3-way catalyst system in clearing the HC 0.41, CO 3.4 and NOx 0.4 g/mile standards is roughly equal to that of the oxidation catalyst in meeting the standards of HC 0.41, CO 3.4 and NOx 1.0 g/mile. Even if the compression ratio is increased or if improvements are made in combustion performance, with the oxidation catalyst system there is no way to avoid a decrease in fuel economy of at least 5%.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy as Compared to 1981 Vehicles or Nissan's Estimates

In their status report* on emission control systems, Nissan discussed four areas in which they were doing research and development work in order to improve fuel economy. These included:

1. Accessory drive program;
2. Engine efficiency improvement program;
3. Tire test program; and
4. Lubricant test program.

The following are excerpts from Nissan's discussion of the accessory drive and engine efficiency programs. Nissan did not discuss the impact on emissions as a result of their tire and lubricant test programs.

II.F.3 Accessory Drive Programs

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* Ibid., pages 251 to 253.

The air-conditioner compressor, the power steering pump, the alternator and the water pump are included in the category of engine assisted equipment. For the 280ZX model, we studied what effect the air-conditioner compressor and the power steering pump have on catalyst inlet emissions and fuel economy.

In contrast to engines without compressors, engines equipped with them showed an overall worsening of 10 to 12% for HC and CO emissions, 30% for NOx and 11% for fuel economy.

II.F.4 Engine Efficiency Improvement Program

Improving engine efficiency is important not only in achieving better fuel economy but also in reducing emissions. As a basic step toward attaining these goals, the research to upgrade engine efficiency is a vital part of our overall research and development activities.

In our efforts to improve engine efficiency, we have carried out basic research on raising the engine compression ratio and on lowering the pumping loss. We have also been proceeding with applied research of the engine efficiency improvement program to other projects such as "0.4 gpm NOx Research Program." The following is our status of this research work.

In addition we are presently making every effort to develop a new engine which will achieve a reduction in mechanical friction loss.

(1) High Compression Ratio Engine

As we explained in our 0.4 g/mile NOx Research Program report (September 1979 to January 1981), we found that improved combustion by the high compression ratio made it possible to expand the region of stable combustion under heavy EGR conditions and to lessen partial-load fuel consumption at the equivalent NOx level. At the low engine speed WOT condition, however, it is necessary to retard the ignition timing to prevent engine knocking, and this results in lowering the engine torque by approximately 10%.

To solve this problem we have been making a concerted effort to develop the technology needed for raising the engine mechanical octane number. These findings indicate that when engine torque and fuel economy are taken into account, a combustion pattern having a short heat generation period and slow initial combustion is effective in suppressing knocking.

The fuel economy level of an experimental vehicle mounted with 10:1 compression ratio engine is about 5% better than that with 8.5:1 compression ratio engine. However, it is estimated that this improvement in fuel economy will be lowered somewhat, when the engine is actually used on production vehicles and countermeasures are implemented to reduce the increased HC emissions and to compensate for the deterioration in driveability due to the decreased torque in low engine speed ranges.

Nissan has shown a significant improvement in fuel economy, 27% over the last three years, while achieving the required emissions performance, for their 119 CID engine. Most of this improvement is attributable to the introduction of new cylinder heads which speed-up the burning rate within the combustion chamber*. The engine which utilizes the new cylinder head is referred to as the NAPS-Z engine. The new cylinder head incorporates the following features:

1. Compact hemispherical combustion chamber;
2. Dual spark plugs; and
3. Redesigned intake porting to induce swirl and turbulence.

The net result of these changes is to improve the burning rate of the fuel by about 50% if there is no exhaust gas recirculation, and about 65% with the intake charge diluted 20% with recirculated exhaust gas, as shown in figure Nissan-2. Major improvements in combustion stability, with heavy EGR, were made, permitting dramatic improvements in both economy and emissions*, (see figure Nissan-3).

An equal contribution, to improved economy and emissions, was obtained by optimizing the control of ignition timing, fuel-air ratio and EGR.

Basically, this was accomplished by mapping the steady-state response of the engine, in terms of economy and emissions, as functions of fuel-air ratio, ignition timing, and EGR rate, at selected speed-load points representing the EPA Urban Cycle.

Detailed refinements to the engine, to improve mixture distribution, and to enhance performance during cold-start and warm-up, account for the rest of the progress made by Nissan.

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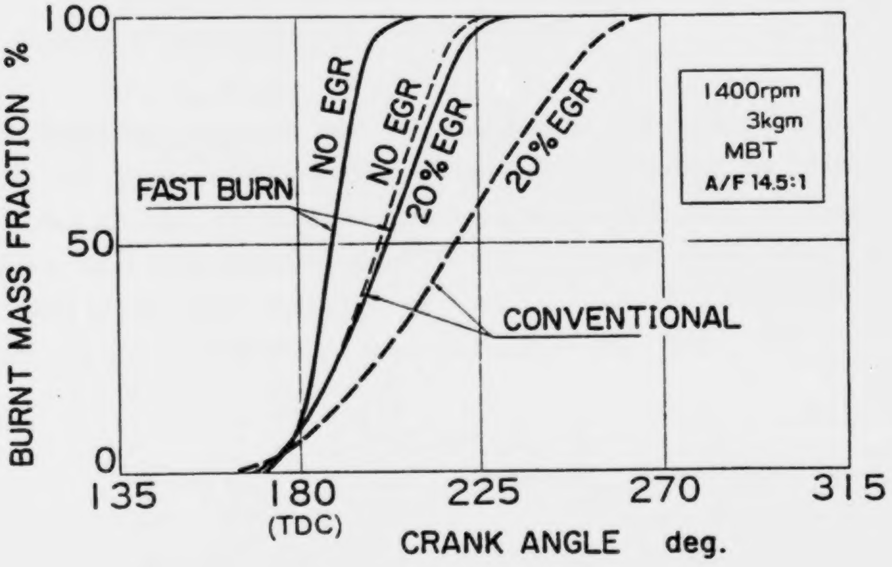
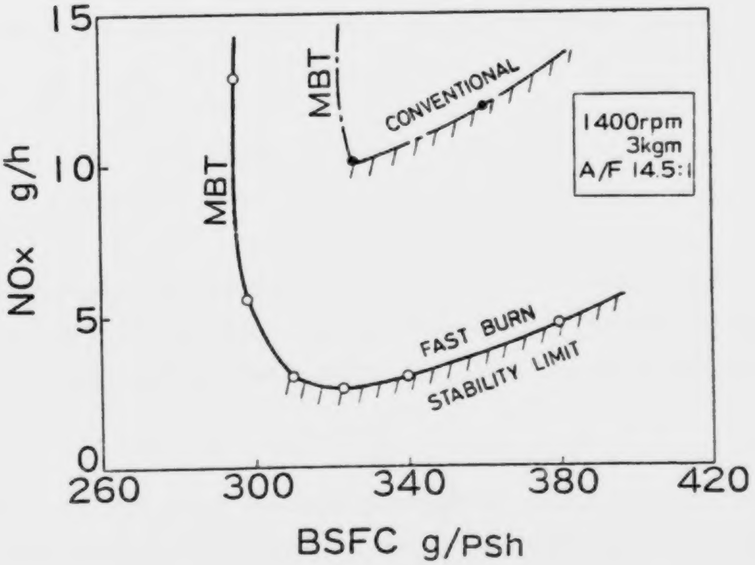
* The Fast Burn with Heavy EGR, New Approach for Low NOx and Improved Fuel Economy; SAE paper no. 780006. Figures 11, and 15, and pages 8 and 10 respectively

Figure Nissan - 2



Effect of fast burn on combustion duration

Figure Nissan - 3



Improved fuel economy combined with low NO_x emission achieved by fast burn engine

In the case of the 2.8 liter (168 CID) engine used in the Datsun 280 series cars, the same progress with respect to emission control has taken place, however, the improvement in fuel economy is small.

Nissan employs a microprocessor to control, electronically, the following parameters:

1. Fuel/air ratio;
2. Spark timing;
3. Exhaust gas recirculation;
4. Air intake at idle.

In addition to emissions standards, heavy emphasis was placed on driveability.* The system is described schematically in figure Nissan-4. It will be noted that this engine uses a "three-way" catalyst for exhaust after treatment, rather than the simple oxidation catalyst used on the smaller engines.

In the case of the smaller Nissan engines of 1.2, 1.4, and 1.5 liter capacity (75.5, 85.0, and 90.8 CID), the picture is qualitatively similar to that of the 2.8 liter engine, i.e., the emissions standards have been met with no noteworthy effect on fuel economy. Nissan has recently announced that this family of smaller engines will be modified to incorporate the fast-burn features, found on the 119 CID engine, for the Japanese market in 1982.

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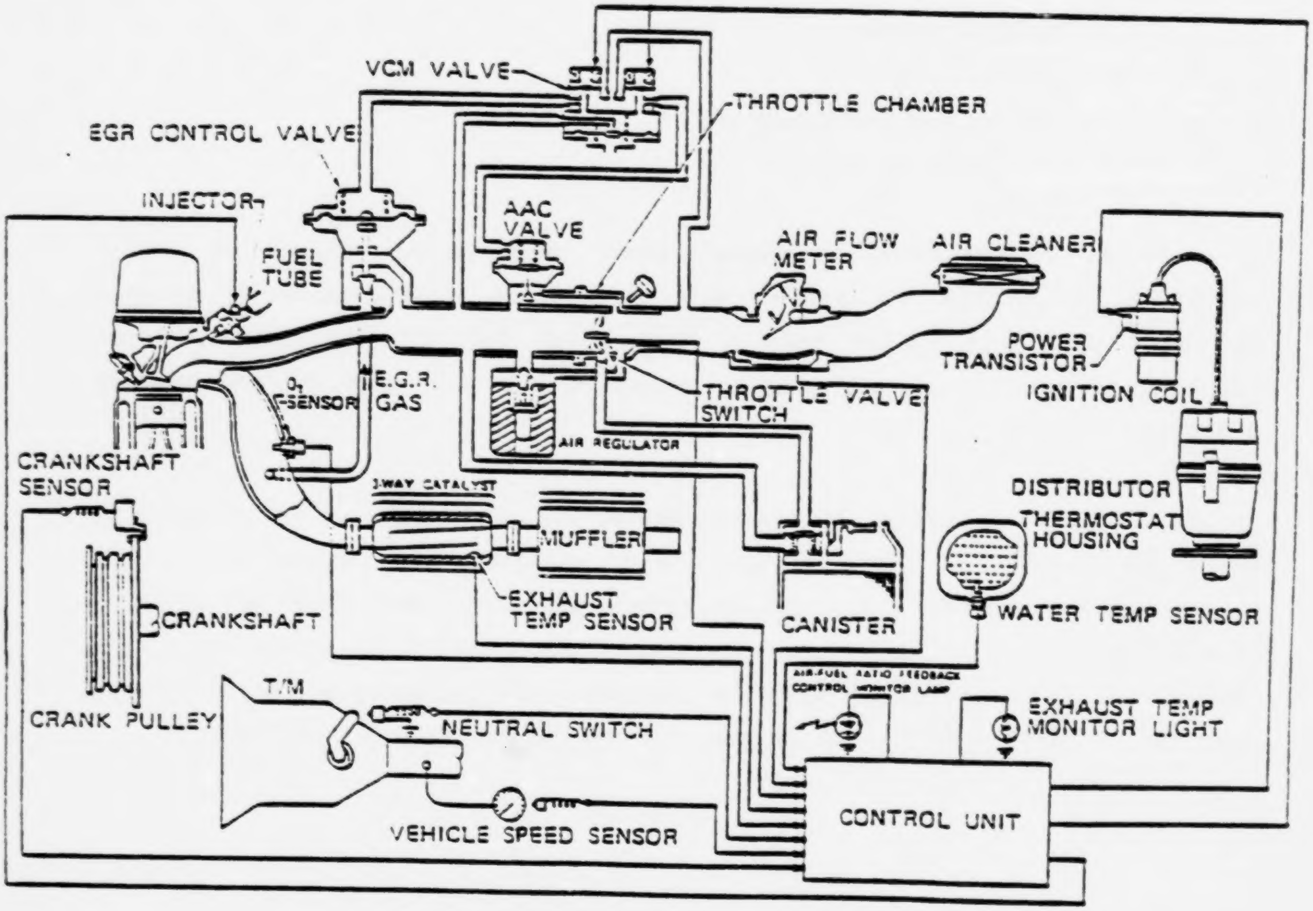
* "Nissan ECCS (Microprocessor Control System) Boosts Fuel Economy," First International Automotive Fuel Economy Research Conference; Oct. 31 to Nov. 2, 1979, pages 212 to 219.

Figure Nissan - 4


VCM VALVE
THROTTLE CHAMBER
EGR CONTROL VALVE
INJECTOR
FUEL TUBE
AAC VALVE
AIR FLOW METER
AIR CLEANER
POWER TRANSISTOR
IGNITION COIL
O₂ SENSOR
E.G.R. GAS
THROTTLE VALVE SWITCH
AIR REGULATOR
CRANKSHAFT SENSOR
DISTRIBUTOR
THERMOSTAT HOUSING
3-WAY CATALYST
MUFFLER
EXHAUST TEMP SENSOR
CANISTER
WATER TEMP SENSOR
CRANKSHAFT
CRANK PULLEY
T/M
NEUTRAL SWITCH
AIR-FUEL RATIO FEEDBACK CONTROL MONITOR LAMP
EXHAUST TEMP MONITOR LIGHT
CONTROL UNIT
VEHICLE SPEED SENSOR

Schematic of Electronic Concentrated Engine Control System

V. F. Honda

1. Honda's Statements Concerning the Relationship between Emissions and Fuel Economy

Honda stated that a basic characteristic of their CVCC engine is low specific fuel consumption (i.e., high fuel economy) and low NOx emissions when bench tested.* Honda also reported that the use of EGR on their CVCC engine could:**

1. Decrease NOx emissions but increase HC emissions.
2. Increase fuel economy, and
3. Improve driveability.

Honda controls the increase in HC emissions by using a catalyst.** Thus, with the use of EGR and a catalyst, Honda says that they are able to control emissions without adversely affecting their fuel economy.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy as Compared to 1981 Vehicles or Honda's Estimates.

A. New Engines

1. While Honda has not supplied EPA with any development data on a three-cylinder engine, "Automotive News" reports that Honda is planning to introduce in Japan, during autumn of 1981, a small car powered by such an engine. That report speculates that the

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*"Honda's NOx Research Program - 1979 Annual Research Period Plan," March 25, 1979, page 10.

**"Honda's Effort and Progress in Meeting the 1981 and Subsequent Model Year Emission Standards," March 20, 1981, page 7.

new car will be based upon the Civic but will be smaller.* Honda has neither confirmed nor denied these reports.

2. Diesel Engine

Honda is continuing to conduct basic research and to analyze available information on Diesel engines.** Honda has been bench testing a 4 cylinder, 4 cycle, 2.2 liter Diesel engine.*** They have not, however, provided EPA with any of their conclusions or test results.

B. Three-Way Catalysts

Honda's primary candidate for a system to meet the 1983 California emissions standards is their stratified charge engine (CVCC) equipped with EGR, a closed-loop carburetor, and a three-way catalyst (system D). Honda has experimented with two other systems, one is similar to their 1981 models (i.e., CVCC with EGR, an open-loop carburetor, and oxidation catalyst); the second system uses a conventional engine with EGR, a closed-loop carburetor, and three-way catalyst. However, Honda found that their primary system was superior to the other two in driveability, fuel economy, and emissions. This system has been tested in a 2125 pound car equipped with a manual five-speed transmission and a 1.5 liter engine. Honda reports that this vehicle met the research target levels (0.41 HC, 3.4 CO, 0.41 NOx); however, no emission or fuel economy data was provided.

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*"Automotive News," March 23, 1981, page 30.

**"Honda's Effort and Progress in Meeting the 1981 and Subsequent Model Year Emission Standards," March 20, 1981, page 19.

***"Honda's Emission Control Status Report," January 13, 1978, page 0.4-15.

"However," Honda states, "in view of the urgent need for complying with the 1983 California standard, development and refinement work for a modified system (system D1) has been initiated based upon 1981 model production hardware."* Honda has not provided EPA with a description of this modified system; although, the typical emission results that Honda provided on these two systems** leads the EPA technical staff to believe that their primary system is superior to the modified (D1) system for emissions. (See table Honda-1.)

Honda states that they are continuing to refine their primary system.* While Honda claims to have confirmed the durability of their new three-way catalyst up to 50,000 miles, they are still experiencing problems with cars equipped with the automatic transmissions. Honda reports, "Automatic transmission models equipped with the system D currently fail the applicable CO standard because their high gear ratio causes the carburetor secondary passages to frequently operate. A change of the gear ratio results in a reduction of fuel economy."***

Honda's current work on three-way catalysts centers on the following four projects:****

1. Development of the three-way catalyst for both systems D and D1,
2. Evaluation of Pt/Rh ratio,
3. Study of substituting Pd for Pt, and
4. Study of improving catalyst durability at elevated temperature.

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* "Honda's Effort and Progress in Meeting the 1981 Standards," March 20, 1981, pages 37-38.
** Ibid., Table 14.
*** Ibid., pages 44-46.
****Ibid., page 55.

		System D	System D_1					
MODEL		CIVIC	CIVIC	CIVIC	CIVIC	CIVIC	ACCORD	ACCORD
ENGINE (1)		1.5	1.3	1.3	1.5	1.5	1.8	1.8
TRANS.		5MT	5MT	3AT	5MT	3AT	5MT	3AT
TEST WT. (lbs)		2125	2000	2125	2125	2125	2625	2625
N/V		41.0	50.7	60.3	43.3	58.7	48.7	56.0
LA-4 Emiss. (g/mi)	CO	1.84	2.72	2.54	2.51	3.04	3.81	4.28
	HC	0.254	0.29	0.32	0.32	0.32	0.28	0.24
	NOx	0.312	0.29	0.31	0.28	0.28	0.21	0.23

Table Honda - 1*

TYPICAL EMISSION TEST RESULTS OBTAINED BY
USING AGED CATALYSTS

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* Ibid., Table 14.

3. The Effects of Known Technology which Helps Quantify Single or Multiple Calibrations or Vehicle Description Changes

A. Engine Improvements

Honda is continuing to study variations of their stratified charge combustion chamber. Honda reports that they have evaluated several such systems. One type, called a "branched conduit" system, is similar to Honda's CVCC system except that the auxiliary combustion chamber is connected to the main combustion chamber by a relatively long torch passage oriented toward the approximate center of the chamber. Honda states that this system "is able to further reduce exhaust emissions, HC and NOx, in particular, with no adverse effect on fuel consumption under the wide range of engine operating conditions."* Honda also reported test results from other auxiliary stratified charge combustion chamber engines identified simply as Type 1, Type 2, and Type 3. Honda did not describe these systems in detail; however, their test results indicate that these systems can yield emissions and fuel economy results superior (during some operating conditions) to Honda's standard CVCC engine.** Some of these features have already been incorporated into Honda's 1981 models.

B. EGR

Incorporation of EGR on the CVCC system, according to Honda, enables them to increase the compression ratio and advance the spark timing, thus resulting in improved fuel economy and driveability.*** For the 1981 model year, Honda modified the back-pressure EGR, that they used on their 1980 California models, to allow for more recirculation of exhaust gas; this increased capacity of the EGR valve was combined with an improved stratified charge combustion chamber design. Honda states that, "This EGR system [combined with the aforementioned improved CVCC engine] contributed to improved fuel economy and driveability by:

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* S.Yagi, et al., "A New Combustion System in the Three-Valve Statified Charged Engine, "SAE Paper 790439, February, 1979, page 1.

** "Honda's Emission Control Status Report," January, 1978, pages 80-26 to 80-28.

*** "Honda's Effort and Progress in Meeting the 1981 and Subsequent Model Year Emission Standards," March 20, 1981, pages 29-32.

1. The combination of a high EGR rate and near stoichiometric engine operation at high loads, in order to improve driveability while reducing NOx emissions, and

2. The combination of CVCC's lean combustion characteristics and a low EGR rate at low loads, in order to improve fuel economy and driveability."*

C. Oxidation Catalyst

Honda reports that, "The increase in fuel economy and reduction in NOx emissions, achieved through the use of the improved combustion chamber design, are accompanied by an increase in HC emissions, the control of which is done by an improvement in oxidation catalyst. Specifically, HC conversion efficiency was improved by 2% through an increase in the specific surface area of substrates, that is, by the use of 400 cell substrates as compared with 300 cell for 1980 system."**

D. Engine Friction Reduction

For 1982, Honda reports, "An additional fuel economy gain is sought by reducing mechanical friction due to piston rings or oil seals, and also by controlling idle speed by engine loads."***

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* Ibid., page 7.
** Ibid., pages 7-8.
*** Ibid., pages 30-32.

E. Carburetor

Honda hopes to minimize the fuel penalty during decelerations by replacing the throttle opener with a deceleration control device.*

F. Reduction of Aerodynamic Drag and Vehicle Weight

"For some [1982] models, "Honda states, "minor modifications of body are made in order to reduce aerodynamic drag as well as vehicle weight, such as adopting high strength steel and plastics."*

G. General Comments

The EPA technical staff attempted to evaluate the effects on emissions and fuel economy of adding EGR and an oxidation catalyst to Honda's CVCC engine. The most dramatic change was with the non-California version of the 81 C.I.D. (1.3 liter) Civic. The results of all tests performed at EPA's laboratory and Honda's laboratory, are shown on the following chart:**

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* Ibid., pages 30-32.

** EPA/MFR Test Data Base as of February 10, 1981.

	Manual 5-Speed			Manual 4-Speed		
	1980	1981	Percent Change	1980	1981	Percent Change
HC	0.256	0.182	-28.9%	0.220	0.189	-14.1%
CO	3.84	1.18	-69.3%	3.08	1.35	-56.2%
NOx	1.20	0.75	-37.5%	1.21	0.80	-33.9%
MPG_u	27.75	33.56	+20.9%	27.30	33.33	+22.1%
MPG_h	38.40	44.65	+16.3%	35.65	41.93	+17.6%
MPG_c	31.71	37.78	+19.1%	30.52	36.72	+20.3%

Thus, Honda was able to substantially reduce emissions while at the same time substantially increasing fuel economy. Honda was also able to increase the rated horsepower (from 55 to 60 HP) by raising the compression ratio from 7.9 to 8.8.

The changes in fuel economy from 1980 to 1981 with Honda's other engines were less dramatic and less consistent. Honda's Accord equipped with a 1.8 liter engine and manual 5-speed transmission actually lost about 3% in MPG_c from 1980 to 1981.*

Using approximations for Honda's sales-weighted fuel economy (CAFE) (the official values are not yet available), we found that Honda was able to increase its CAFE from 1980 to 1981 by 3% (from 30.0 to 30.9 mpg), even though the average weight increased by 2%.** However, compared to similar 1981 model year vehicles of all other manufacturers, Honda's vehicles had an average poorer fuel economy (by 3 to 4%) in each inertia weight class, as shown on the following table:

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* Ibid.

** Foster, Murrell, Loos, "Light Duty Automotive Fuel Economy... Trends through 1981, "SAE Paper number 810386, February 1981, pages 14-16.

Table Honda-2*

Comparison of Honda's 1981 Fuel Economy Versus the Entire 1981 Fleet By Weight

Inertia Weight	Honda's Avg. MPG$_c$	Avg. of All Car's MPG$_c$	Percent Diff. (Relative to Fleet)
2000	35.81	36.96	-3.1%
2250	33.13	34.47	-3.9%
2500	28.11	29.37	-4.3%

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* Ibid.

V. G. Volkswagen

I. Volkswagen's Statements Concerning the Relationship between Emissions and Fuel Economy

A. VW Study

Volkswagenwerk AG (VW) investigated the impact of emission standards on fuel economy. This program was conducted under a contract between VW and the U.S. Department of Transportation - Transportation Systems Center. The following results of that study were reported by VW in SAE Paper number 790230, titled "Impact of Emission Standards on Fuel Economy and Consumer Attributes."

In addition to testing uncontrolled vehicles, VW also tested vehicles targeted to meet the following four standards:

	Emissions (g/mi)		
Standard	HC	CO	NOx
Federal 1976	1.5	15.	3.1
California 1976	0.9	9.0	2.0
Federal 1981	0.41	3.4	1.0
Research Goal	0.41	3.4	0.4

Each of the five (5) groups included a 2250 pound inertia weight Rabbit equipped with a 1.3 liter engine (never sold in the U.S.), a 2250 and a 2500 pound Rabbit each equipped with a 1.6 liter engine, and a 3000 pound Audi. The Audis used in the uncontrolled case and with the 1976 standards were equipped with 1.6 liter, 4-cylinder engines; the ones used with the 1981 standard and the research goal were equipped with 2.2 liter, 5-cylinder engines.

The technologies that the VW engineers chose to use were:

Standard	Technology
Uncontrolled	Carburetor
1976 Federal	Carburetor, Oxidation Catalyst
1976 California	Carburetor, Oxidation Catalyst
1981 Federal	Fuel Injection, 3-Way, Closed-loop
Research Goal	Fuel Injection, 3-Way, Closed-loop

VW then tested the uncontrolled vehicles as well as those equipped with oxidation catalysts and carburetors. VW found that no additional modifications were required of the catalyst equipped cars in order to meet the 1976 standards.

Before testing the fuel injected vehicles, VW set engineering goals for the emissions that were more stringent than the standards. Those more stringent goals were "formulated to ensure that once they had been attained at the end of the development period, all the mass production vehicles made along the same lines will meet the exhaust emission standards, no matter when or where they are tested within the initial 50,000 miles of their service life."* VW chose as goals for HC and CO values that were one-half the respective standards; and for NOx, one-fourth of the applicable NOx standard.

The fuel injected vehicles then were modified and tested until the emissions, driveability, and fuel economy were considered satisfactory. As a criterion for satisfactory fuel economy, VW used the fuel economy of the uncontrolled version as the goal. In addition to changes in ignition timing, the modifications included in some cases adding a proportional EGR system and a secondary air pump.

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* H. Oetting, "Impact of Emission Standards on Fuel Economy and Consumer Attributes," SAE Paper No. 790230, February, 1979, page 2.

The results of the testing indicates that the Audi vehicles suffered a substantial loss in fuel economy in meeting either the 1981 standards or the research goal. The loss was more than 20% relative to those meeting the 1976 standards. VW believes that the loss in fuel economy is primarily "due to the fact that friction in these engines is higher because of the fifth cylinder."*

The three types of Rabbits (1.6 liter at 2250 and 2500 pounds and 1.3 liter at 2250 pounds) exhibited two consistent fuel econony trends:

1. All the Rabbits which were targeted to meet the research standard suffered a loss in fuel economy of between 4.2% to 10.9% relative to the corresponding Rabbits which were targeted to meet the 1981 Federal standards.

2. All the Rabbits which were targeted to meet the 1981 Federal standards displayed a fuel economy improvement of between 2.1% to 7.5% relative to the corresponding Rabbits which were targeted to meet either of the 1976 emission standards.

VW speculated that the reason the vehicles targeted to meet the 1981 standards exceeded the fuel economy performance of similar vehicles which met far less stringent standards was due to "the introduction of new technological features, such as lambda control and K-Jetronic fuel injection."*

VW then studied these vehicles with respect to unregulated emissions, noise, startability, and performance. VW concluded that:

1. "[T]he emission control concepts featuring K-Jetronic fuel injection and 3-way catalysts are capable of meeting the advanced standards, furnishing good fuel economy, low HCN emissions, and a stable SO_4 emission rate."**

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* Ibid., pages 5-6.

** Ibid, page 7.

2. "[T]he noise emissions of modifications 13 through 16 [i.e., those vehicles which were designed to meet the 1981 Federal emission standards] are lower than those of other vehicles meeting less stringent exhaust emission standards."*

3. The "sophisticated concepts introduced to meet advanced emission standards are superior to conventional concepts regarding their startability and driveability."*

4. "[L]eaving aside the 5-cylinder engine, the performance of the vehicles which meet the advanced standards is slightly inferior to that of the others. This is because gradeability is related to maximum torque in a practically linear function, and by some sort of accident it was the carburetor-type vehicles which always had the highest torque. There is no way of explaining this by the emission control concept."**

Finally, VW analyzed the effects on the cost of the engine of those vehicles which met the more stringent emission standards. They determined, that in order to meet either the 1981 Federal standards or the research goal (the components are the same for both standards), the cost of the engine (not the entire vehicle) would be increased by between 64% and 89% over the corresponding uncontrolled vehicles, and by between 38% and 56% over the corresponding vehicles meeting the 1976 Federal standards.***

B. EPA Comments on the VW Study

VW assumed that a closed-loop, three-way catalyst, fuel injected system was necessary to meet the 1981 Federal standards; however, a number of open-loop, carbureted vehicles have been certified as meeting those standards.

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* Ibid., page 8.
** Ibid., page 9.
*** Ibid., page 11.

The engineering goals (of 1/2 the applicable HC and CO standards and of 1/4 the applicable NOx standard) were conservative. The deterioration factors associated with the 1981 model year, closed-loop, 3-way catalyst, fuel injected, gasoline powered Federal vehicles equipped with either 1.7 liter, 4-cylinder VW engines or 2.2 liter, 5-cylinder Audi engines are all 1.000.

Thus, VW's selection of the required technology and engineering (emission) goals was possibly more conservative than necessary. However, VW did show, that, for an increase in cost, the fuel economy, noise, and driveability could all be improved while at the same time substantially reducing the emissions.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy as Compared to 1981 Vehicles or VW's Estimates.

A. Formula E

VW will be introducing a package of several features that will be called "Formula E" (for Economy). This package will consist of one or more (depending on the model) of:

1. Signal to Shift

VW is developing an electronic device that will signal the driver when to shift for optimal fuel economy at various speeds and loads. This option has been available on VWs in Europe since December, 1980. It is anticipated that this option will soon be available on some U.S. Rabbits.*

EPA is currently testing such vehicles, but not enough data has been generated to assess the effect of this option. However, VW reported to EPA that, "Experimental results show that observing the electronically given shifting signals can lead to fuel savings of 6 to 10% in the urban cycle, depending on engine and gearbox adjustment. This is due simply to correct 'engine management' and does not entail any diminuation of performance. Practical driving results confirm these findings."*

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* "Wards Engine Update," March 15, 1981, page 6.

2. Automatic Engine Shut-Off

VW is testing a system that will switch off the engine during idling and deceleration. VW claims this system will increase urban fuel economy. VW states, "This [system] would mean a 25% increase in spark ignition engine efficiency and an 18% increase in Diesel engine efficiency."**

The engine is restarted from kinetic energy which was stored in a spinning flywheel that turns the crank. A second clutch disconnects the flywheel when the car stops or coasts. Simultaneously, the computer shuts off the ignition and fuel flow. When the driver steps on the gas, the second clutch recouples the flywheel to the crankshaft, fuel is injected, and the spark plugs fire.

VW engineer Paulus Heidemeyer was quoted as saying, "Shutting off the engine when its power isn't needed can cut fuel consumption by 20-25% in city and suburban driving, when frequent stops and starts are made."* A test vehicle was reported to have yielded higher fuel economy on the FTP cycle and produced lower emissions than a similar vehicle with a conventional power train.*

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* "Status Report of Volkswagenwerk AG and Audi NSU," May 1981, page 191.

** Ibid., page 186.

*** Norbye, "VW's Stop/Start 21st-Century Car," Popular Science, July 1980, pages 76-77.

A drawback of this system is that there is no provision for running accessories while the engine is stopped. Thus, it might not be suitable for cars equipped with air conditioning, power steering, or power brakes.*

3. Overdrive Top Gear

VW has redesigned and renamed their gearboxes. The 4-speed manuals will be called "3 + E" (i.e., 3-speed plus an economy gear), and the 5-speed manuals will be called "4 + E." The gear ratios within the transmission will be changed so that the maximum speed is reached in the next to last gear, with the top gear becoming an economy overdrive gear. VW claims, "In normal operation, the savings amount to 10 to 13% on 3 + E gearboxes and 5 to 6% on 4 + E gearboxes."** VW made no predictions for fuel savings on either EPA's urban or highway test cycles.

4. Aerodynamic Aids and Weight Reduction

While reducing neither aerodynamic drag nor weight is new, these concepts will be incorporated in the Formula E package.***

B. Combustion Chamber Redesign and Knock Sensing

VW is developing a combustion chamber which provides a higher compression ratio, an increase of 2 to 3 units.**** VW is working on a knock limit sensing system in conjunction with the development of high compression concepts. By using a computer to closely match the spark advance to the knock limit, VW hopes to improve efficiency.*****

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*Norbye, "VW's Stop/Start 21st-Century Car," Popular Science, July 1980, pages 76-77.

**"Status Report of Volkswagenwerk AG and Audi NSU," May 1981, page 189.

***Ibid., page 186.

****Ibid., page 168.

*****Ibid., page 161.

C. Three-Cylinder Diesel

VW has built and is testing a 1.2 liter, direct injection, Diesel engine with supercharger. VW believes that direct injection could possibly provide a "10-15% increase in fuel economy over what is already a miser, the swirl chamber Diesel."* Even though VW has a 1.3 liter, 4-cylinder engine already available in Europe, they decided to make this engine a 3-cylinder instead of 4, in order to reduce frictional losses.*

VW is investigating the advantages of a turbocharger versus a mechanically driven supercharger versus natural aspiration.*

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*Ibid., page 31.

V. H. Toyo Kogyo (Mazda)

1. Toyo Kogyo's Statements Concerning the Relationship between Emissions and Fuel Economy

Toyo Kogyo (TK) did not state that there was a well defined relationship between emissions and fuel economy. However, TK did state that meeting the 1983 California standards (0.41 HC, 7.0 CO, 0.4 NOx) will result in a fuel economy penalty even though the emission control system they are developing to meet those standards has a "potential to reduce the fuel consumption and exhaust emission."* TK did not quantify the amount of the expected loss in fuel economy, nor did they provide EPA with data to substantiate their claim of a loss in fuel economy.

2. New Technology or Developments which Could Provide a Change in the Relationship between Emissions and Fuel Economy as Compared to 1981 Vehicles or TK's Estimates.

A. New Engines

1. Rotary Engine

TK is the only manufacturer of automotive rotary (Wankel) engines sold in the U.S. TK began using a 3-way catalyst with an open-loop carburetor and an air pump on their rotary models for the 1981 model year. They intend to use this same system for 1982. For 1983, TK plans to use a closed-loop carburetor with a 3-way catalyst, an air pump, and EGR.** TK provided no estimates or test data on this new system.

TK reported that they are studying a supercharged version of their rotary.*** Industry sources speculate that the supercharged version of the twin-rotor Wankel engine will offer more horsepower, greater low-end torque, and improved fuel economy.*** The speculation is that this vehicle would not be available prior to the 1983 model year.*

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* "Mazda Status Report," February 1981, pages 64-65.

** "Mazda Status Report," February 1981, page 3.

*** "Ward's Engine Update," Volume 6, Number 12, June 25, 1980, page 6.

2. Diesel Engine

With the 1981 model year, TK introduced its first passenger car Diesel engine in TK's Japanese Luce series. This 4 cylinder, 2.2 liter engine is available only in TK's Japanese market; however, industry sources believe that it is similar to the engines that TK has agreed to sell to Ford in the next year or so for the U.S. market.** TK claims that this Diesel vehicle has a fuel economy of 51.7 mpg when tested at a steady 37.5 mph**(not an EPA test cycle).

TK reported that work on a direct-injection combustion system for their Diesel engines is a project, second in importance only to TK's work in turbocharging small engines.***

TK has not provided EPA with any emissions or fuel economy data on their Diesel powered vehicles. Some emission and fuel economy results from a TK engine in a Ford vehicle are shown in section V.B, Ford.

3. Small (2- and 3-Cylinder) Engines

TK reports that they are investigating the use of 4-, 3-, and 2-cylinder engines for use in 4-passenger, 2-passenger, and 2 + 2 small cars. The engine displacements range to below 1 liter (61 CID).**** "Automotive News" reports that TK will begin producing small cars, powered by a 3-cylinder engine, for sale in the U.S. beginning with the 1985 model year. These cars would be sold under the Mazda, Ford, and Mercury nameplates. The report predicts an urban fuel economy for these cars of between 40 to 50 mpg.**

---

* "Automotive News," November 17, 1980, pages 2 and 44.
**" "Ward's Engine Update," Volume 6, Number 20, October 15, 1980, page 6.
*** "Ward's Engine Update," Volume 6, Number 17, September 1, 1980, page 6.
****"Ward's Engine Update," Volume 6, Number 17, September 1, 1980, page 6.

Another report indicates that this car will be front-wheel drive, and that the engine displacement will be between 1 and 1.2 liters (61 to 74 CID).* TK did not submit any data on this vehicle to EPA.

B. Closed-Loop Carburetor

TK plans to employ a closed-loop carburetor, an air pump, EGR, and a dual 3-way catalyst on all of their passenger cars beginning with the 1983 model year.** This system has been tested by TK in a vehicle with 2250 pound test weight and equipped with a 1.5 liter engine and manual transmission. TK states that neither the fuel economy results nor the driveability obtained thus far with this system (see table TK-1) met their goal.***

Table TK-1

Comparison of Fuel Economy and Emissions of the Closed-Loop Test Vehicle to the Fuel Economy and Emissions of a Comparable 1981 Model Year Open-Loop Vehicle.

	HC	CO	NOx	MPG_u	MPG_h	MPG_c
Closed-Loop Test Vehicle***	0.22	4.0	0.31	33.4	--	--
1981 TK Data Vehicle****	0.224	1.03	0.49	34.5	41.6	37.4

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* "Ward's Engine Update," Volume 7, Number 2, January 15, 1981, pages 1 and 4.

** "Mazda Status Report," February, 1981, page 3.

*** Ibid, pages 66-67.

****"EPA Test Car List, 1981 Second Edition."

Even though this one test vehicle experienced a drop in urban fuel economy of 3.2% (relative to its 1981 model year counterpart), the effect of this system on overall fuel economy cannot be determined since TK did not submit highway test data (MPG_h).

TK believes that the loss in fuel economy and driveability is, "due to the insufficient controlling performance for the air/fuel ratio and EGR, the insufficient catalytic efficiency, the choking-up of the EGR passage by the carbon and so forth. And thus, the refinement of the control system of the mixture and EGR, the combustion improvement, the catalyst screening and so forth are considered important."* TK says they plan to improve those components during the 1982 model year based on the results of the analysis done during 1981.**

C. Combustion Chamber Improvements

TK reports:

> "We have taken an approach to mainly accelerate combustion in the engine with the help of increased swirl and squish, and have achieved the excellent results through the MSH (Masked Seat Head) method."
>
> "We intend to continue pursuing the improvement of fuel economy still further by means of modifying the combustion chamber configuration in the future."***
>
> "In addition, the following items will be considered, too:
>
> To make the combustion chamber more compact.
> To make the compression ratio higher.
> Development of [a]DIS (Dual Induction System).
> The selection of spark plug location."****

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* "Mazda Status Report," February, 1981, page 67.
** Ibid., page 33.
*** Ibid., page 70.
****Ibid., page 69

D. Electronic-Controlled EGR

Backpressure type EGR provides increased control over the type not using backpressure to simultaneously reduce NOx and to stabilize driveability. TK plans to develop an electronic-controlled EGR system which will provide greater control accuracy of EGR than the backpressure type provides.*

3. The Effect of Known Technology Which Helps Quantify Single or Multiple Calibrations or Vehicle Description Changes.

TK plans to gradually replace the main moving parts of their engines (such as rotors for rotary engines and connecting rods for conventional engines) with lighter weight parts. TK says that this will decrease frictional losses and thus increase engine efficiency.**

TK also plans on studying four other systems that can affect fuel economy:**

1. Using pulse air instead of an air pump,
2. Fuel injection,
3. Electronic ignition, and
4. Knock controller.

For the 1981 model year, TK increased the fuel economy of their GLC and RX-7 models over the corresponding 1980 models. (See table TK-2.)

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*Ibid., page 69.
**Ibid., page 33.

Table TK-2*

Fuel Economy of 1980 and 1981 Mazda Vehicles

	1980			1981		
	MPG_u	MPG_h	MPG_c	MPG_u	MPG_h	MPG_c
GLC						
A3-Trans	27	34	30	30	37	32
M4-Trans	30	42	34	35	43	38
M5-Trans	29	39	33	35	45	39
RX-7						
A3-Trans	16	24	19	19	24	21
M5-Trans	17	28	20	21	30	24

TK claims that they improved the fuel economy of their conventional engine (used in the GLC) by:**

1. Change in emission control system
   Although we had been using a single catalyst + air injection + EGR up to the 1980 year models, we adopted on the 1981 year models a dual catalyst + air injection + EGR so as to improve the fuel economy and meet the more stringent NOx standard.

2. Vehicle weight reduction
   By changing the GLC to a front wheel drive model, we were able to reduce the weight from 2,250 lbs to 2,125 lbs.

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* EPA/DOE Gas Mileage Guide.

** "Mazda Status Report" February, 1981, page 32.

3. Power-to weight reduction and drivetrain programs
The GLC engine was increased in piston displacement from 86.4 CID to 90.9 CID, thus having adequate power/weight ratio. So, N/V ratio was changed from 57.0 to 54.1 in top gear and from 47.1 to 43.1 in overtop, thus making this engine a high speed type, thereby improving the fuel economy.

4. Accessory drive program
The cooling fan was changed to a motor driven type, hence reducing the propulsion loss of the fan.

TK says that the improved fuel economy of their rotary engine (used in the RX-7) resulted from:*

1. Engine efficiency
We improved fuel economy and reduced emissions by improving the gas sealing, modifying the engine (the ignition system and intake system in particular), operating the engine at a leaner mixture, making the combustion more stable and optimizing the catalyst system. In order to optimize all three systems, we made studies on reduction in raw HC, improvement in thermal efficiency, best design of the catalytic converter, selection of a catalyst best suited to the rotary engine, reduction in the temperature of the exhaust gas entering the catalyst, and adjustment of the air/fuel mixture.

2. Reduction in vehicle air resistance
The shape of the front grille of the car was redesigned so as to reduce the air resistance of the car body, and the load to be applied to a chassis-dynamometer was lowered from 8.0 hp/50 MPH for 1980 to 7.1 hp/50 MPH for 1981.

3. Vehicle weight reduction
We reduced the weight of the car body, engine and their related parts, thereby lowering the test weight from 2,750 lbs to 2,625 lbs.

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* Ibid., page 34.

The EPA technical staff has generated approximations of TK's sales-weighted fuel economy value (the official values are not yet available), and we found that TK's fleet average fuel economy increased from 26.3 mpg in 1980 to 31.1 for their 1981 models (an increase of 18%).* Comparing, by weight, TK's 1981 vehicles with conventional (not rotary) engines to the average of all 1981 model year vehicles, yields the following table:

Table TK-3**

Comparison of Toyo Kogyo's 1981 Fuel Economy Versus the Entire 1981 Fleet By Weight (Excluding Rotary Engines)

Inertia Weight	TK's Avg. MPG_c	Avg. of All Car's MPG_c	Percent Diff. (Relative to Fleet)
2000	38.59	36.96	+4.4%
2250	34.52	34.47	+0.1%
2750	30.75	27.17	+13.2%

Thus TK was able to increase the fuel economy of its conventional vehicles so that they were more fuel efficient than most other similar vehicles. TK's rotary engine vehicles average 24.27 MPG_c compared to 29.37 MPG_c for all 2500 pound inertia weight cars.** These data are somewhat biased against the Mazda vehicles since their equivalent test weight is 2625 pounds and they are being compared to a group of vehicles which includes lighter vehicles.

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* Foster, Murrell, Loos, "Light Duty Automotive Fuel Economy ... Trends through 1981," SAE Paper number 810386, February 1981, pages 14-16.

** Ibid.

V. I. American Motors

1. American Motors' Statements Concerning the Relationship between Emissions and Fuel Economy

Quoting their latest status report,* "American Motors is vendor dependent with regard to emission control systems. These include catalytic converters, air injection pumps, ignition systems, carburetors, EGR systems, and electronic control modules." Because of this dependency, and the necessity of prior financial commitment to the vendors, AMC's development program has been limited in scope to evaluation of emissions control components, evaporative emissions control, driveability, and fuel economy.

Their emissions control program is one of evaluation of prototype, vendor-supplied, control hardware installed on suitably modified production cars. "Once a particular emission control strategy, and associated components have been selected, there is an inherent relationship between the achieveable fuel economy and the emissions standards as a result of the control system constraints. Consequently, there has been no separate reportable effort or data in the area of fuel economy improvement."

With respect to a 0.41 HC, 3.4 CO, 0.4 NOx standard, they stated "AM has been unable to demonstrate, even on a research vehicle that these standards can be met with any control system planned for 1981 through 1983." Work is planned to investigate different fuel systems, catalyst configurations, and refinement of control strategies. Confidential treatment was requested for the details of AMC's production vehicle development program.

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* American Motors Corporation Efforts and Progress to Meet 1981 and Subsequent Model Year Light-Duty Vehicle Emission Standards; March, 1981.

General Comments

A substantial body of test data was provided in the status report; however, the vehicle descriptions and the details of the test configurations were so sketchy that the EPA technical staff could not draw conclusions from the AMC efforts. It is possible to consider the recent (1979-1981) history of AMC cars with the 258-2V engine (table AMC-1), as tested by EPA. This is the only passenger car engine common to model years 1979, 1980, and 1981. Since 1979, control of HC and CO emissions has been improved significantly (up to 66% and 60% respectively), and urban fuel economy has improved 5 to 10%. Some improvement in NOx control was observed for the manual transmission cars, but not for those with automatic transmissions. No major change in weight occurred, other than that attributable to the finer test weight increments used since 1980. There is not a demonstratable adverse effect on fuel economy attributable to the improvements in emission control.

In the case of the 151-2V engine, which entered production in 1980, there have been no changes in emissions control requirements for 1981, because of waivers. Consequently, as shown in table AMC-2, there have been no major changes in the emissions and fuel economy performance.

Table AMC-1

Emissions and Fuel Economy of AMC Cars
258-2V Engine

Model		HC EMISSIONS (g/mi)			CO EMISSIONS (g/mi)			NOx EMISSIONS (g/mi)			URBAN ECONOMY (MPG_u)			
Year	Trans.	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Avg Test Weight
1979	A3	.565	.61	.50	8.7	9.5	7.9	1.125	1.29	0.96	16.5	17	16	3375
	M4	.468	.52	.40	4.8	4.9	4.7	1.645	1.73	1.56	17.5	18	17	
1980	L3	.27	.33	.25	4.55	6.65	3.0	1.30	1.38	1.16	17.67	18	17	3396
	M4	.2165	.27	.183	2.36	4.0	1.38	1.347	1.38	1.29	18.0	18	--	
1981	L3	.193	.280	.132	3.450	4.71	0.79	1.11	1.24	0.92	18.6	19	18	3264
	M4	.186	.204	.171	2.653	5.27	2.12	.865	1.21	0.81	18.75	20	18	

Table AMC-2

Emissions and Fuel Economy of AMC Cars
151-2V Engine

Model		HC EMISSIONS (g/mi)			CO EMISSIONS (g/mi)			NOx EMISSIONS (g/mi)			URBAN ECONOMY (MPG_u)			
Year	Trans	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Avg Test Weight
1980	A3	.201	.232	.170	2.335	2.65	2.02	1.505	1.69	1.32	20.5	21	20	3125
	M4	.255	.260	.250	3.80	4.7	2.8	1.18	1.21	1.15	22	22	22	2938
1981	A3	.097	--	--	1.13	--	--	1.59	--	--	20	--	--	3250 sample
	M4	.1593	.189	.124	2.637	3.86	1.31	1.787	1.90	1.70	22.67			2958

Appendix 1

Prediction of Federal Test Procedure Results from Hot Emissions Data

Appendix 1

Prediction of Federal Test Procedure Data from Hot Emissions Data

The test procedures used to measure exhaust emissions from new motor vehicles are described in Part 86 of the Code of Federal Regulations. The Federal Test Procedure is commonly referred to as the FTP. The FTP specifies the test fuel, driving schedule, vehicle preparation, test site ambient conditions and other details which are intended to give the test results a high degree of scientific accuracy.

A brief discussion of the exhaust emission measurement portion of the FTP is required at this point. The exhaust emissions of a light-duty vehicle are measured while the vehicle is operated on a chassis dynamometer.

The vehicle exhaust gas is collected while the vehicle is being operated on the dynamometer. The exhaust gas stream is diluted with ambient air and a sample of this dilute mixture is collected during each phase for analysis. The dynamometer run is divided into three phases. A composite gas sample is collected in a separate bag for each phase. Bag one contains the sample collected during the "transient" phase of the cold start test which is the first 505 seconds of the driving schedule. The second bag sample is collected from the 505th second of the driving schedule until its end at 1372 seconds. This is the "stabilized" phase of the test. Bag three is collected from the time the vehicle is restarted following the ten minute hot soak until the 505th second of the driving schedule. The three bags are sometimes referred to as the cold transient (ct) bag, the stabilized (s) bag, and the hot transient (ht) bag.

The bag samples are analyzed and calculations are performed to determine the grams of emissions per test phase. The final reported test results are then computed using the grams per test phase data from the bag samples and the following equation:*

---

* Code of Federal Regulations, Part 86.144-78 As of July 1, 1979.

$$Y_{wm} = 0.43\,((Y_{ct} + Y_s)/(D_{ct} + D_s)) + 0.57((Y_{ht} + Y_s)/(D_{ht} + D_s))$$

Where: Y_{wm} = Weighted mass emissions of each pollutant, i.e., HC, CO, NOx or CO_2, in grams per vehicle mile.

Y_{ct} = Mass emissions as calculated from Bag 1, in grams per test phase.

Y_{ht} = Mass emissions as calculated from Bag 3, in grams per test phase.

Y_s = Mass emissions as calculated from Bag 2, in grams per test phase.

D_{ct} = The measured driving distance during Bag 1, in miles.

D_{ht} = The measured driving distance during Bag 3, in miles.

D_s = The measured driving distance during Bag 2, in miles.

The final value of the measured emissions is obviously a function of the design of the test procedure. Emissions values determined using another test procedure or a modified version of the FTP, may or may not be related to the FTP emissions.

Automotive research and development programs will often utilize an abbreviated form of the FTP. For example, if a researcher was only interested in a vehicle's exhaust emissions, the portion of the FTP which measures evaporative emissions may be omitted. Another common abbreviated form of the FTP is called a "hot" FTP. The implied meaning of a "hot" FTP is that the 12 to 36 hour soak period before the dynamometer run was deleted. Instead the dynamometer run is started with the vehicle in a "warmed up" or "hot" condition. Elimination of the many hours long soak period prior to the start of the dynamometer run allows many "hot" FTP's to be run in an eight hour working day compared to only a part of a single emission test in accordance with the FTP.

The cold transient and stabilized phases of the dynamometer run are performed with a warmed-up vehicle. The driving schedule will be identical for both the "hot" FTP and Bags 1 and 2 of the official FTP. However, because of the difference in thermal preconditioning between these two test procedures, the final emission values may be vastly different.

FTP equivalent emissions and fuel economy results are sometimes calculated from steady-state engine data. These calculated projections are often (or should be) qualified by a statement like the following:

> It should be noted that these calculations do not account for the warm-up portion of the FTP drive cycle, the engine transients, or...*

This statement above should alert users of such data that the possibility exists that the calculated emissions and fuel economy may be different from actual FTP results. SAE paper number 800396, "The Exhaust Emission and Fuel Consumption Characteristics of an Engine During Warmup - A Vehicle Study", said the following in reference to gasoline fueled vehicles:

> The relative contribution of pollutants emitted during vehicle warmup has been magnified because the outstanding performance of contemporary catalytic converters has nearly eliminated the pollutants emitted from fully warm vehicles.

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* Trella, Thomas J., "Fuel Economy Potential of Diesel and Spark Ignition - Powered Vehicles in the 1980s" SAE 810514.

Many vehicle components influence the exhaust emissions as a function of the vehicle's thermal state. For example, all, or nearly all, model year 1981 gasoline fueled light-duty vehicles utilize a catalytic converter in their emission control system. The conversion efficiency of a catalyst increases with higher temperature. Exhaust emissions are reduced with greater conversion efficiency. Diesel engines in production now do not have any catalytic devices to treat the exhaust.

Another design feature of gasoline fueled vehicles which effects exhaust emissions as a function of thermal pre-conditioning is the start-up enrichment system. This cold start enrichment and the initial inactivity of the catalyst during Bag 1 of the FTP contribute a large percentage of the total CO and HC measured in a FTP.

Emission test data from certification testing were analyzed to determine what, if any, relationships exist between Bag 1 and Bag 3 emissions. Figure 1-1 presents a summary of the selection criteria for the main data base which was analyzed. Additionally, this figure shows how the main data base was divided into ten subgroups.

Correlation matrices were generated for the ten data sets shown in figure 1-1. These matrices are presented in table 1-3 to table 1-12. Some correlation coefficients (r values) have been compiled from these matrices and listed in tables 1-1 and 1-2 for easier reference in the following discussion.

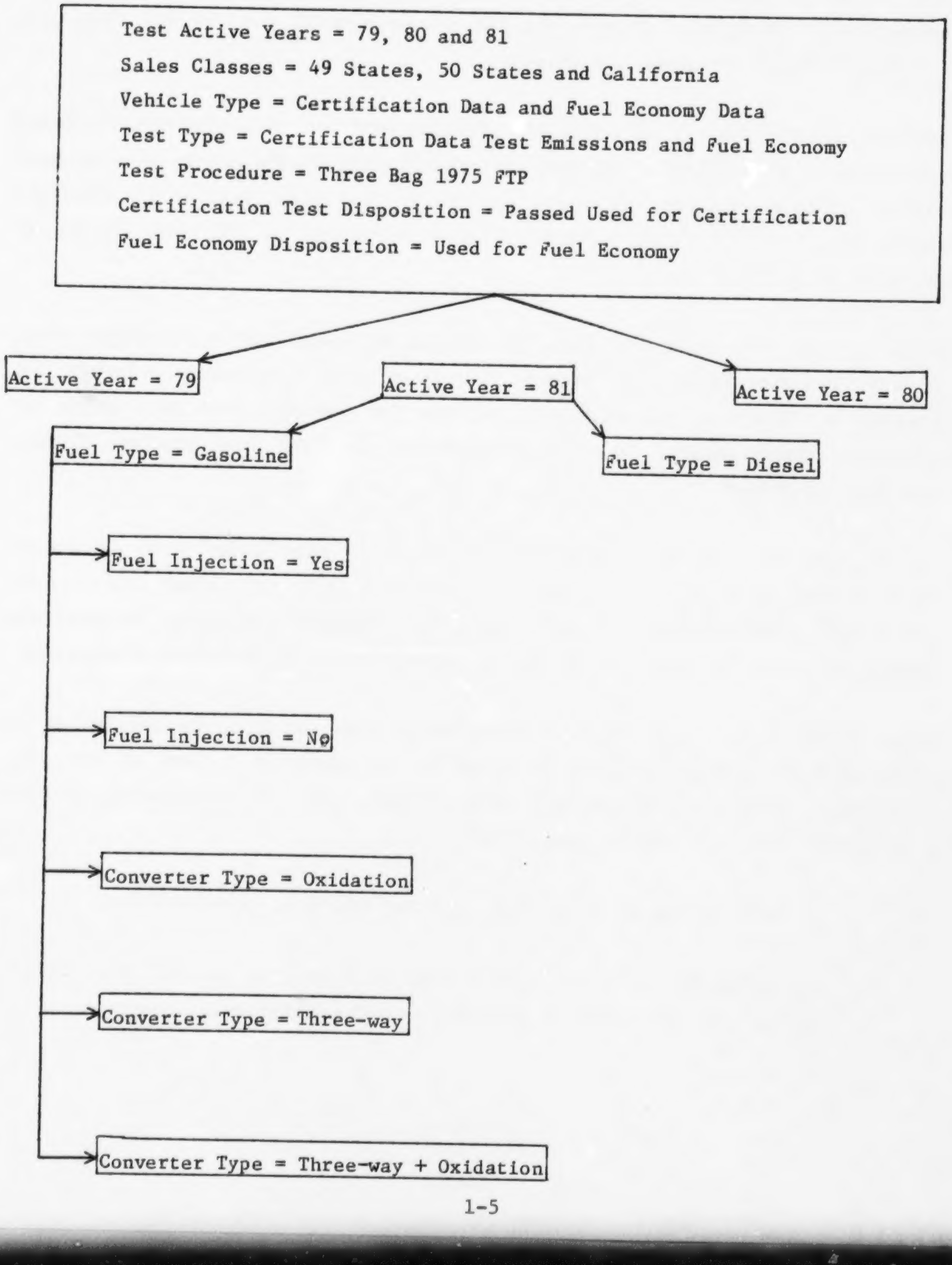
These correlation coefficients could provide some guidance in developing an emission test procedure which is based on an abbreviated form of the FTP. Conversely, these data may provide some insight into the relationship between a so-called "hot FTP" and an actual FTP.

The data of table 1-1 seem to substantiate the following observations:

1. Bag 3 NOx correlates to some extent ($r > .85$) to the FTP NOx for all cases. The r is greater when NOx is not catalytically controlled.

Figure 1-1

Data Base Description


Test Active Years = 79, 80 and 81
Sales Classes = 49 States, 50 States and California
Vehicle Type = Certification Data and Fuel Economy Data
Test Type = Certification Data Test Emissions and Fuel Economy
Test Procedure = Three Bag 1975 FTP
Certification Test Disposition = Passed Used for Certification
Fuel Economy Disposition = Used for Fuel Economy
Active Year = 79
Active Year = 81
Active Year = 80
Fuel Type = Gasoline
Fuel Type = Diesel
Fuel Injection = Yes
Fuel Injection = No
Converter Type = Oxidation
Converter Type = Three-way
Converter Type = Three-way + Oxidation

able

Correlation Coefficients (r)

1981 Active Year

Variable	Gasoline	Diesel	Oxidation Cat.	3-Way Cat.	3-W +O.C.	Fuel Injected (Non-Diesel)	Not Fuel Injected
B_1HC vs. FTPHC	.7238	.3519	.7357	.9162	.6705	.9129	.6937
B_1CO vs. FTPCO	.8700	.9430	.8719	.9120	.8309	.9339	.8518
B_1NOX vs. FTPNOx	.8035	.9121	.8746	.7546	.6890	.8517	.7766
B_3HC vs. FTPHC	.6744	.5228	.7662	.5433	.6426	.5322	.7133
B_3CO vs. FTPCO	.5965	.9043	.6115	.6260	.6067	.3788	.6132
B_3NOx vs. FTPNOx	.9286	.9105	.9757	.8859	.8593	.9217	.9130

	Active Year 1979, All	Active Year 1980, All	Active Year 1981, All
B_1HC vs. FTPHC	.6527	.3346	.3512
B_1CO vs. FTPCO	.8015	.8623	.8767
B_1NOx vs. FTPNOx	.7644	.8661	.7800
B_3HC vs. FTPHC	.8578	.3764	.5439
B_3CO vs. FTPCO	.7789	.6614	.5957
B_3NOx vs. FTPNOx	.9011	.9353	.9333

Table 1-2
Correlation Coefficients (r)
1981 Active Year

Variable	Gasoline	Diesel	Oxidation Cat.	3-Way Cat.	3-W + O.C.	Fuel Injected (Non Diesel)	Not Fuel Injected
B_3HC vs. B_1HC	.0985	.6457	.1929	.2916	.0152	.2817	.1140
B_3CO vs. B_1CO	.1927	.8656	.2047	.3029	.1305	.1081	.1739
B_3NOx vs. B_1NOx	.7401	.9365	.8669	.6986	.5192	.7654	.6816

	Active Year 1979, All	Active Year 1980, All	Active Year 1981, All
B_3HC vs. B_1HC	.4826	.0852	.1927
B_3CO vs. B_1CO	.4342	.2616	.2181
B_3NOx vs. B_1NOx	.7465	.8485	.7687

Table 1-3

Active Year 1979
All

```
<CORRELATION  BYST VAR=23,24,1-3,11-19,51,53,54,101-103 STRAT=V50>

CORRELATION MATRIX  <79> TAYR:79

N= 600  DF= 598  R@ .0500= .0801  R@ .0100= .1051

   VARIABLE

  23.DISP      1.0000

  24.RTHP       .8133   1.0000

   1.FTPHC      .0083  -.0773   1.0000

   2.FTPCO      .1287   .0617    .5429   1.0000

   3.FTPNOX     .1895   .0546    .4584    .3075   1.0000

  11.B1HC       .2298   .1994    .6527    .6520    .3764   1.0000

  12.B1CO       .3816   .2882    .2902    .8015    .2494    .6996   1.0000

  13.B1NX       .0226  -.0276    .2644    .2566    .7644    .3179    .1801   1.0000

  14.B2HC      -.1551  -.1875    .8555    .3858    .3654    .3162    .0301    .2244   1.0000

  15.B2CO      -.2731  -.2492    .5160    .6516    .1818    .2302    .1097    .2054    .5960   1.0000

  16.B2NX       .2868   .1029    .4357    .2013    .8617    .2677    .1925    .3826    .3241    .0430   1.0000

  17.B3HC      -.1010  -.1393    .8578    .5207    .3965    .4826    .2073    .2547    .8281    .5132    .3413   1.0000

  18.B3CO       .0087  -.0598    .5066    .7789    .2642    .3959    .4342    .1969    .4083    .5564    .2303    .6336

  19.B3NX       .0883   .0245    .4253    .3555    .9011    .3988    .2680    .7465    .3629    .2803    .6232    .3997

  51.ETW        .9217   .7802   -.0127    .1101    .1367    .1862    .3515   -.0125   -.2006   -.2805    .2404   -.1345

  53.ETWSDISP  -.8954  -.6837   -.0412   -.1198   -.1806   -.2489   -.3691   -.0339    .0958    .2619   -.2837    .0541

  54.ETWSRTHP  -.3304  -.7123    .1050   -.0342    .0502   -.1771   -.1453    .0097    .0741    .0912    .1008    .0287

 101.B1SB3.HC   .0504   .2012   -.3001   -.1287   -.2125    .1398    .1219   -.0731   -.3808   -.2631   -.2423   -.4637

 102.B1SB3.CO   .0313   .1041   -.0837   -.0706   -.0057   -.0118    .0181    .0388   -.0766   -.1033   -.0328   -.1087

 103.B1SB3.NX  -.0924  -.0545   -.1614   -.1225   -.3074   -.0951   -.1156    .0193   -.1161   -.0710   -.3378   -.1391
               23.     24.      1.        2.        3.        11.      12.      13.      14.      15.      16.      17.
               DISP    RTHP     FTPHC     FTPCO     FTPNOX    B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

  18.B3CO      1.0000

  19.B3NX       .2366   1.0000

  51.ETW        .0244    .0373   1.0000

  53.ETWSDISP   .0127   -.0573   -.7454   1.0000

  54.ETWSRTHP   .0788   -.0190   -.1956    .3250    1.0000

 101.B1SB3.HC  -.3558   -.1788    .0874   -.0402    -.2375    1.0000

 102.B1SB3.CO  -.1433    .0013    .0606   -.0321    -.0943     .1920    1.0000

 103.B1SB3.NX  -.0690   -.3915   -.0664    .0546    -.0068     .1338     .0171    1.0000
               18.      19.      51.      53.       54.        101.      102.      103.
               B3CO     B3NX     ETW      ETWSDISP  ETWSRTHP   B1SB3.HC  B1SB3.CO  B1SB3.NX
```

Table 1-4

Active Year 1980
All

```
CORRELATION MATRIX  <80> TAYR:80

N= 450  DF= 448  R@ .0500= .0925  R@ .0100= .1213

  VARIABLE

 23.DISP         1.0000
 24.RTHP          .7658   1.0000
  1.FTPHC         .2401    .1327   1.0000
  2.FTPCO        -.0982   -.0298    .1789   1.0000
  3.FTPNOX        .3081    .0343    .1733   -.1929   1.0000
 11.B1HC         -.0535    .2118    .3346    .4645   -.2603   1.0000
 12.B1CO         -.0308    .0915    .1135    .8623   -.1527    .6481   1.0000
 13.B1NX          .2130    .0210    .0663   -.1674    .8661   -.0985   -.0948   1.0000
 14.B2HC          .3243    .1178    .4709   -.0832    .3393   -.1855   -.1723    .2741   1.0000
 15.B2CO         -.1595   -.1906    .1845    .3812   -.0765   -.1914   -.0646   -.1523    .1729   1.0000
 16.B2NX          .3643    .0575    .2440   -.2310    .9305   -.3540   -.2142    .6570    .3407   -.0339   1.0000
 17.B3HC          .0806   -.0254    .3764    .3875    .0179    .0852    .1856    .0446    .3262    .1777   -.0361   1.0000
 18.B3CO         -.0972   -.1626    .1196    .6614   -.1596   -.0003    .2616   -.1589    .0214    .5065   -.1621    .6060
 19.B3NX          .2056   -.0025    .0949   -.0962    .9353   -.1671   -.0565    .8485    .2938   -.0611    .7739    .0794
 51.ETW           .9115    .7441    .2618   -.0877    .2717   -.0821   -.0375    .1678    .2640   -.1067    .3511    .0122
 53.ETWSDISP     -.9137   -.6830   -.2069    .0867   -.2698   -.0329   -.0315   -.2103   -.3294    .2724   -.3108   -.0897
 54.ETWSRTHP     -.2838   -.7149    .1490   -.0674    .2163   -.4135   -.2228    .1193    .0975    .2315    .2683    .0579
101.B1SB3.HC     -.1815    .0798   -.1566    .0388   -.3364    .4893    .2220   -.2351   -.4692   -.1872    .3503   -.4840
102.B1SB3.CO      .0901    .0949    .0657    .0340    .1109    .2493    .2200    .1334   -.0320   -.2285    .0719   -.1061
103.B1SB3.NX     -.0797   -.0116   -.0936   -.0655   -.3538    .1548   -.0161   -.0927   -.1921   -.1469   -.3625   -.1015
                 23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
                 DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

 18.B3CO         1.0000
 19.B3NX         -.1094   1.0000
 51.ETW          -.0930    .1493   1.0000
 53.ETWSDISP      .1199   -.1739   -.7504   1.0000
 54.ETWSRTHP      .1501    .1493   -.1526    .3345   1.0000
101.B1SB3.HC     -.2767   -.3004   -.1136    .1491   -.2433   1.0000
102.B1SB3.CO     -.2514    .1235    .0749   -.1149   -.0914    .1491   1.0000
103.B1SB3.NX     -.0387   -.4509   -.0572    .0382   -.0633    .2257   -.0370   1.0000
                 18.      19.      51.      53.      54.      101.     102.     103.
                 B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX
```

Table 1-5

Active Year 1981

All

```
CORRELATION MATRIX  <81> TAYR:81

N= 378  D. - [illegible]  R@ .0500= .1009  R@ .0100= .1323

   VARIABLE

 23.DISP       1.0000

 24.RTHP        .7536   1.0000

  1.FTPHC       .3455    .2078   1.0000

  2.FTPCO       .0356    .1400    .3119   1.0000

  3.FTPNOX      .2638  -.1010    .3082  -.1230   1.0000

 11.B1HC        .1006    .3661    .3512    .4890  -.3897   1.0000

 12.B1CO        .0213    .1764    .1539    .8767  -.2005    .6033   1.0000

 13.B1NX        .3072    .0636    .1780  -.0910    .7800  -.1951  -.0965   1.0000

 14.B2HC        .1791    .1031    .6983    .2640    .2696    .0343    .0790    .1985   1.0000

 15.B2CO        .0077  -.0444    .4169    .4618    .1217  -.0419    .0586  -.0519    .3816   1.0000

 16.B2NX        .2055  -.1784    .3180  -.1317    .9457  -.4541  -.2483    .5655    .2379    .1899   1.0000

 17.B3HC        .1867    .1765    .5439    .3301    .0100    .1927    .1701    .0728    .6407    .1732  -.0229   1.0000

 18.B3CO        .0577    .0401    .2527    .5957    .0126    .0664    .2181    .0022    .3269    .4736    .0397    .5031

 19.B3NX        .2580  -.0360    .2855  -.0876    .9333  -.2752  -.1169    .7687    .2971    .0587    .8038    .0256

 51.ETW         .9189    .7543    .3271    .0207    .2563    .0854  -.0117    .3147    .1498    .0636    .1984    .1210

 53.ETWSDISP  -.9240  -.7003  -.2954  -.0672  -.2033  -.1417  -.0819  -.2630  -.1512    .0533  -.1401  -.2439

 54.ETWSRTHP  -.1942  -.6895    .0743  -.2621    .4951  -.5124  -.3468    .2594    .0151    .1390    .5573  -.1900

101.B1SB3.HC  -.1420    .0707  -.2228    .0064  -.3469    .4206    .1855  -.2407  -.4307  -.2196  -.3494  -.4779

102.B1SB3.CO   .0683    .1431  -.1210    .0447  -.0599    .2472    .3221    .0759  -.1751  -.3492  -.1318  -.2533

103.B1SB3.NX  -.0744    .0618  -.1130    .0116  -.3891    .1342    .0168  -.1933  -.2001    .0174  -.3594  -.0316
               23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
               DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC


 18.B3CO       1.0000

 19.B3NX       -.0351   1.0000

 51.ETW         .0427    .2401   1.0000

 53.ETWSDISP  -.0583  -.2155  -.7738   1.0000

 54.ETWSRTHP  -.0824    .3808  -.1087    .2738   1.0000

101.B1SB3.HC  -.2785  -.3065  -.0711    .1591  -.2134   1.0000

102.B1SB3.CO  -.3979  -.0025    .0748  -.0975  -.1545    .3897   1.0000

103.B1SB3.NX  -.0224  -.4689    .0079    .1027  -.1241    .1849  -.0047   1.0000
               18.      19.      51.      53.      54.      101.     102.     103.
               B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX
```

Table 1-6

Active Year 1981

Gasoline

```
<CORRELATION  BYST VAR=23,24,1-3,11-19,51,53,54,101-103 STRAT=V50:81*V36:(1,2,6,7,17),(8,9)>
CORRELATION MATRIX  <1> TAYR:81*FTYP:(1,2,6,7,17)
N= 335  DF= 333  R@ .0500= .1072  R@ .0100= .1406

   VARIABLE
  23.DISP        1.0000
  24.RTHP         .8148    1.0000
   1.FTPHC        .2851     .2977    1.0000
   2.FTPCO        .0691     .0658     .4820    1.0000
   3.FTPNOX       .2344     .0277     .1627     .1336    1.0000
  11.B1HC         .2234     .3077     .7238     .3899    -.0276    1.0000
  12.B1CO         .0939     .0819     .3896     .8700     .1758     .4555    1.0000
  13.B1NX         .2807     .1207     .1061     .0102     .8035    -.0303     .0576    1.0000
  14.B2HC         .1750     .1344     .7342     .3213     .2753     .1186     .1562     .1840    1.0000
  15.B2CO        -.0654     .0104     .3555     .6291    -.1075     .1803     .2558    -.1560     .3632    1.0000
  16.B2NX         .1540    -.0535     .1413     .1963     .9095    -.0455     .2062     .5307     .2480    -.0482    1.0000
  17.B3HC         .2074     .1316     .6744     .2873     .1860     .0985     .0899     .1411     .6802     .2497     .1932    1.0000
  18.B3CO         .0575     .0072     .3111     .5965     .1092     .0083     .1927     .0346     .3447     .5370     .1878     .4958
  19.B3NX         .2290     .0621     .1848     .0955     .9286     .0137     .1636     .7401     .2930    -.1123     .7578     .1459
  51.ETW          .9304     .8295     .2698     .0751     .1525     .2529     .0919     .2617     .1346    -.0285     .0552     .1549
  53.ETWSDISP    -.9237    -.7247    -.2688    -.0711    -.2453    -.1953    -.1068    -.2652    -.1542     .0846    -.1760    -.2433
  54.ETWSRTHP    -.3462    -.7563    -.2039    -.0579     .1453    -.2210    -.0352     .1103    -.0883    -.1022     .1533    -.0732
 101.B1SB3.HC    -.1205     .0101    -.1548    -.0962    -.2299     .3271     .0570    -.1736    -.4228    -.1443    -.2239    -.5698
 102.B1SB3.CO     .1061     .1050    -.0627    -.0263     .1076     .1576     .2572     .1519    -.1567    -.3089     .0430    -.3085
 103.B1SB3.NX    -.0645     .0280    -.0718    -.0445    -.3930     .0506    -.0714    -.1585    -.1868     .0755    -.3830    -.0658
                 23.       24.       1.        2.        3.        11.       12.       13.       14.       15.       16.       17.
                 DISP      RTHP      FTPHC     FTPCO     FTPNOX    B1HC      B1CO      B1NX      B2HC      B2CO      B2NX      B3HC

  18.B3CO        1.0000
  19.B3NX         .0179    1.0000
  51.ETW          .0480     .1487    1.0000
  53.ETWSDISP    -.0503    -.2415    -.7942    1.0000
  54.ETWSRTHP    -.0119     .1070    -.3049     .3584    1.0000
 101.B1SB3.HC    -.3232    -.2034    -.0190     .1685    -.0338    1.0000
 102.B1SB3.CO    -.4324     .1228     .1286    -.1112    -.0188     .3517    1.0000
 103.B1SB3.NX    -.0399    -.4643     .0419     .1116    -.0219     .1466    -.0405    1.0000
                 18.       19.       51.       53.       54.       101.      102.      103.
                 B3CO      B3NX      ETW       ETWSDISP  ETWSRTHP  B1SB3.HC  B1SB3.CO  B1SB3.NX
```

Table 1-7

Active Year 1981
Fuel Injected (non-Diesel)

```
<CORRELATION  BYST VAR=23,24,1-3,11-19,51,53,54,101-103 STRAT=V50:81*V36:(1,2,6,7,17)*V26:Y,N>

CORRELATION MATRIX  <1> TAYR:81*FTYP:(1,2,6,7,17)*FIN:Y

N= 88  DF= 86  R@ .0500= .2096  R@ .0100= .2732

    VARIABLE

  23.DISP         1.0000
  24.RTHP          .7055    1.0000
   1.FTPHC         .2916     .4620    1.0000
   2.FTPCO         .0085     .2146     .6980    1.0000
   3.FTPNOX        .5712     .3415     .0409    -.0770    1.0000
  11.B1HC          .1622     .3958     .9129     .6589     .0067    1.0000
  12.B1CO          .0496     .2339     .6548     .9339     .0831     .6720    1.0000
  13.B1NX          .4862     .2993    -.0607    -.1818     .8517    -.0710    -.0368    1.0000
  14.B2HC          .2419     .3149     .6647     .4936     .0783     .3575     .3838    -.0125    1.0000
  15.B2CO         -.1383     .0592     .4165     .6569    -.3546     .2983     .3624    -.3558     .4972    1.0000
  16.B2NX          .4775     .1624     .0084    -.1811     .7530    -.0474    -.0598     .3629     .0495    -.3816    1.0000
  17.B3HC          .4623     .3371     .5322     .2410     .0501     .2817     .1561    -.0210     .3661     .1664     .1329    1.0000
  18.B3CO          .0704     .0607     .3405     .3788    -.3292     .1931     .1081    -.3792     .2869     .5631    -.1737     .5130
  19.B3NX          .4807     .4012     .1638     .1783     .9217     .1409     .3168     .7654     .1659    -.1574     .5648     .0266
  51.ETW           .9122     .7787     .3309     .0324     .5113     .2203     .0470     .4590     .2639    -.0508     .3857     .4101
  53.ETWSDISP     -.9002    -.6758    -.2881    -.0348    -.4736    -.1932    -.0834    -.3964    -.1720     .1416    -.4002    -.4440
  54.ETWSRTHP     -.1968    -.7724    -.3986    -.2856    -.0029    -.3931    -.2896     .0449    -.2549    -.1493     .0831    -.1294
 101.B1SB3.HC     -.2082    -.0605    -.0068    -.0186    -.0609     .2249     .0811    -.0558    -.1927    -.1231    -.0648    -.5328
 102.B1SB3.CO     -.0236     .1801    -.0065     .0075     .3071     .1133     .1979     .3592    -.0858    -.2616     .0882    -.3068
 103.B1SB3.NX     -.1130    -.1214     .0045    -.0042    -.3936    -.0119    -.0883    -.1526    -.0448     .1672    -.4113     .1393
                  23.       24.       1.        2.        3.        11.       12.       13.       14.       15.       16.       17.
                  DISP      RTHP      FTPHC     FTPCO     FTPNOX    B1HC      B1CO      B1NX      B2HC      B2CO      B2NX      B3HC

  18.B3CO         1.0000
  19.B3NX         -.2688    1.0000
  51.ETW           .0743     .4461    1.0000
  53.ETWSDISP     -.0709    -.4021    -.7059    1.0000
  54.ETWSRTHP     -.0564    -.1389    -.2250     .3585    1.0000
 101.B1SB3.HC     -.3818    -.0392    -.0899     .2625     .0187    1.0000
 102.B1SB3.CO     -.6123     .3188     .0169     .0216    -.2328     .4090    1.0000
 103.B1SB3.NX      .1611    -.4452    -.0293     .1418     .1656     .0053    -.1301    1.0000
                  18.       19.       51.       53.       54.       101.      102.      103.
                  B3CO      B3NX      ETW       ETWSDISP  ETWSRTHP  B1SB3.HC  B1SB3.CO  B1SB3.NX
```

Table 1-8

Active Year 1981
Not Fuel Injected

```
CORRELATION MATRIX  <2> TAYR:81*FTYP:(1,2,6,7,17)*FIN:N
N= 247  DF= 245  R@ .0500= .1249  R@ .0100= .1636

   VARIABLE
  23.DISP      1.0000
  24.RTHP       .9000   1.0000
   1.FTPHC      .2789    .3058   1.0000
   2.FTPCO      .0765    .0871    .3952   1.0000
   3.FTPNOX     .1337    .0925    .1043    .0738   1.0000
  11.B1HC       .2692    .2346    .6937    .3592    .0608   1.0000
  12.B1CO       .1005    .0814    .2779    .8518    .1311    .4199   1.0000
  13.B1NX       .1835    .1539    .1202  -.0071     .7766    .0696    .0355   1.0000
  14.B2HC       .1524    .2218    .7623    .2210    .1235    .1249    .0422    .1178   1.0000
  15.B2CO     -.0469     .0071    .3387    .6298  -.0861     .1498    .2253  -.1093     .3491   1.0000
  16.B2NX       .0753    .0468    .0731    .1689    .9191    .0523    .2006    .5236    .0752  -.0172    1.0000
  17.B3HC       .1427    .1918    .7133    .2400    .0332    .1140    .0211    .0751    .6919    .2686    .0206   1.0000
  18.B3CO       .0484    .0779    .2968    .6132    .0062    .0311    .1739  -.0090     .2824    .5683    .0829    .4560
  19.B3NX       .1343    .0798    .1018  -.0414     .9130    .0437    .0415    .6816    .1589  -.1389     .7502    .0076
  51.ETW        .9478    .8556    .2766    .1126    .1265    .2604    .1247    .2329    .1594  -.0181     .0507    .1422
  53.ETWSDISP -.9364   -.8197   -.2386   -.0481   -.1251   -.2334   -.0902   -.1708   -.0978     .0772  -.0651   -.1618
  54.ETWSRTHP -.4440   -.7296   -.2270   -.0831   -.0037   -.0915   -.0199     .0044  -.2253   -.1115   -.0235   -.2081
 101.B1SB3.HC -.0531   -.0984   -.1941   -.0385   -.0892     .4101    .1691  -.0963   -.5017   -.1817   -.0628   -.6411
 102.B1SB3.CO   .1468    .0769  -.0769   -.0281     .0897    .1782    .2818    .0926  -.1754   -.3197     .0615  -.3196
 103.B1SB3.NX   .0099    .0075  -.0268     .1257  -.2808     .0346    .0770    .1921  -.1273     .0969  -.3232     .0343
               23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
               DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

  18.B3CO      1.0000
  19.B3NX     -.1002    1.0000
  51.ETW        .0793    .1103   1.0000
  53.ETWSDISP -.0104   -.1347   -.8523    1.0000
  54.ETWSRTHP -.1150     .0215  -.3185     .4457   1.0000
 101.B1SB3.HC -.3412   -.0917   -.0324     .0559    .1511   1.0000
 102.B1SB3.CO -.4456     .0918    .1598  -.1538     .0583    .4126   1.0000
 103.B1SB3.NX   .1268  -.4972     .0923    .0093    .0793    .0679    .0042   1.0000
               18.      19.      51.      53.      54.      101.     102.     103.
               B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX
```

Table 1-9

Active Year 1981
Oxidation Catalyst

```
<CORRELATION  BYST VAR=23,24,1-3,11-19,51,53,54,101-103 STRAT=V50:81*V36:(1,2,6,7,17)*V35>
CORRELATION MATRIX  <2> TAYR:81*FTYP:(1,2,6,7,17)*ESC5:OXID
N= 58  DF= 56  R@ .0500= .2586  R@ .0100= .3357

   VARIABLE
  23.DISP       1.0000
  24.RTHP        .8489   1.0000
   1.FTPHC       .0787   -.0157   1.0000
   2.FTPCO       .1642    .0712    .3148   1.0000
   3.FTPNOX      .2161    .0435   -.1096    .1097   1.0000
  11.B1HC       -.1726   -.1404    .7357    .2934   -.1019   1.0000
  12.B1CO        .1233    .1256    .1727    .8719    .0572    .2920   1.0000
  13.B1NX        .2335    .1011   -.0622   -.0120    .8746   -.1269   -.0842   1.0000
  14.B2HC        .2674    .1151    .6550    .1632   -.0284    .0052    .0200    .0523   1.0000
  15.B2CO       -.1408   -.1792    .3078    .5552    .0126    .2950    .2668   -.1264    .1231   1.0000
  16.B2NX        .1788    .0075   -.1169    .1545    .9603   -.0851    .1068    .7213   -.0577    .0729   1.0000
  17.B3HC        .2745    .0980    .7662    .1685   -.0872    .1929   -.0959    .0156    .7950    .1929   -.1115   1.0000
  18.B3CO        .2743    .0498    .3099    .6115    .1661    .0359    .2047    .2028    .3118    .3427    .1518    .5090
  19.B3NX        .2097    .0373   -.1082    .1186    .9757   -.0854    .0836    .8669   -.0351    .0218    .9016   -.1075
  51.ETW         .9588    .8714    .1533    .2090    .2036   -.1507    .1721    .2415    .3614   -.1114    .1619    .3444
  53.ETWSDISP   -.9261   -.7966    .0145   -.1599   -.2479    .1797   -.0957   -.2445   -.1235    .0862   -.2211   -.1767
  54.ETWSRTHP   -.1603   -.5923    .2485    .2033    .2150    .0285    .0903    .1220    .3473    .1655    .2377    .2910
 101.B1SB3.HC   -.1789    .0814   -.0027    .1177   -.0764    .5886    .3356   -.1670   -.5649    .0073   -.0314   -.5459
 102.B1SB3.CO    .1569    .4559   -.0675   -.0024   -.0898    .1741    .3489   -.0881   -.2118   -.3619   -.0990   -.3215
 103.B1SB3.NX    .0366    .1608    .0588   -.0897   -.3116   -.0595   -.1677    .0432    .1092   -.0649   -.3858    .1716
                23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
                DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

  18.B3CO       1.0000
  19.B3NX        .1345   1.0000
  51.ETW         .2796    .1923   1.0000
  53.ETWSDISP   - 2831   -.2326   -.8481   1.0000
  54.ETWSRTHP    .2590    .2160   -.1422    .2783   1.0000
 101.B1SB3.HC   -.3380   -.0655   -.1470    .1407   -.3536   1.0000
 102.B1SB3.CO   -.4582   -.0610    .2114   -.0860   -.4717    .5981   1.0000
 103.B1SB3.NX    .1233   -.4076    .0723   -.0504   -.2808   -.1218   -.0383   1.0000
                18.      19.      51.      53.      54.      101.     102.     103.
                B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX
```

Table 1-10

Active Year 1981
Three-way Catalyst

```
CORRELATION MATRIX  <3> TAYR:81*FTYP:(1,2,6,7,17)*ESC5:THREEW
N= 119  DF= 117  R@ .0500= .1801  R@ .0100= .2353

   VARIABLE
  23.DISP        1.0000
  24.RTHP         .7212   1.0000
   1.FTPHC        .3287    .4229   1.0000
   2.FTPCO        .3270    .1514    .5600   1.0000
   3.FTPNOX       .4438    .1053   -.0023    .2850   1.0000
  11.B1HC         .2625    .3894    .9162    .5096    .0111   1.0000
  12.B1CO         .3114    .1545    .4902    .9120    .3881    .4959   1.0000
  13.B1NX         .3544    .1779   -.1097    .0996    .7546   -.0713    .1714   1.0000
  14.B2HC         .1111    .2243    .6276    .3542   -.0306    .3152    .2359   -.1278   1.0000
  15.B2CO         .1524    .1221    .4581    .6241   -.1031    .3251    .2744   -.1126    .4902   1.0000
  16.B2NX         .3955   -.0270    .0279    .3027    .8616    .0225    .3735    .3734   -.0093   -.0696   1.0000
  17.B3HC         .4721    .2855    .5433    .3124   -.0076    .2916    .1998   -.0822    .3890    .2906    .0682   1.0000
  18.B3CO         .2251   -.0124    .2790    .6260    .0568    .1790    .3029   -.0185    .1999    .7306    .1628    .4047
  19.B3NX         .3560    .1958    .0576    .2713    .8859    .0688    .3974    .6986    .0480   -.0894    .6141   -.0480
  51.ETW          .8931    .8040    .3670    .2826    .2890    .3027    .2238    .3178    .1682    .2320    .2076    .4208
  53.ETWSDISP    -.8932   -.5833   -.2686   -.3150   -.4743   -.2350   -.3245   -.3130   -.0438   -.0866   -.4619   -.3825
  54.ETWSRTHP      ""92   -.8657   -.3276    .0176    .0862   -.3252   -.0208    .0439   -.1954   -.0154    .1761   -.0986
 101.B1SB3.HC    -.1354    .0419    .1281   -.0257   -.0292    .4042    .0990    .0057   -.2058   -.1660   -.0462   -.5727
 102.B1SB3.CO     .1954    .1590   -.0326    .0793    .3853    .0493    .3001    .3673   -.0744   -.2924    .2526   -.2359
 103.B1SB3.NX    -.0039    .0393    .0647   -.0192   -.3599    .0425   -.0776   -.1025   -.0048    .1210   -.3274    .1680
                  23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
                  DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

  18.B3CO        1.0000
  19.B3NX        -.0735   1.0000
  51.ETW          .2353    .2313   1.0000
  53.ETWSDISP    -.2040   -.3796   -.6490   1.0000
  54.ETWSRTHP     .1985   -.0705   -.4342    .3749   1.0000
 101.B1SB3.HC    -.3056   -.0226   -.0870    .0888   -.1336   1.0000
 102.B1SB3.CO    -.3942    .3936    .0985   -.2155   -.1300    .3136   1.0000
 103.B1SB3.NX     .0482   -.4579    .1253    .1119    .0183    .0686   -.0995   1.0000
                  18.      19.      51.      53.      54.      101.     102.     103.
                  B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX
```

Table 1-11

Active Year 1981
Three-way + Oxidation Catalyst

```
CORRELATION MATRIX  <4> TAYR:81*FTYP:(1,2,6,7,17)*ESC5:TW.O.C
N= 158  DF= 156  R@ .0500= .1562  R@ .0100= .2044

    VARIABLE
 23.DISP        1.0000
 24.RTHP         .8565   1.0000
  1.FTPHC        .1276    .1891   1.0000
  2.FTPCO       -.1859   -.0942    .4354   1.0000
  3.FTPNOX       .1509    .1103    .1478   -.0645   1.0000
 11.B1HC         .3716    .3618    .6705    .3146    .1527   1.0000
 12.B1CO        -.1023   -.0564    .3390    .8309    .0094    .4798   1.0000
 13.B1NX         .2291    .1519    .0880   -.1724    .6890    .1865   -.0742   1.0000
 14.B2HC        -.0816    .0065    .7813    .3218    .1111    .1467    .1025   -.0138   1.0000
 15.B2CO        -.2329   -.1289    .3458    .6545   -.1195   -.0011    .2371   -.1958    .4854   1.0000
 16.B2NX        -.0300    .0082    .0954    .1069    .7961    .0264    .0963    .2132    .1112    .0149   1.0000
 17.B3HC        -.1556   -.0825    .6426    .2678    .0094    .0152    .0117   -.0443    .5979    .3188    .0748   1.0000
 18.B3CO        -.1253   -.0434    .2598    .6067   -.1013   -.0802    .1305   -.1753    .3028    .5470    .0968    .4691
 19.B3NX         .2070    .1263    .1656   -.1405    .8593    .1737   -.0384    .5192    .1505   -.1329    .5362   -.0326
 51.ETW          .9340    .7903    .1012   -.1815    .1681    .3842   -.0846    .3036   -.1087   -.2468   -.0548   -.2150
 53.ETWSDISP    -.9027   -.7426   -.1389    .1956   -.0912   -.3275    .0987   -.1850    .0813    .2488    .0919    .0473
 54.ETWSRTHP    -.2887   -.6675   -.2206   -.1386    .0536   -.1507   -.0395    .1130   -.1675   -.1681   -.0605   -.1451
101.B1SB3.HC     .0432    .0457   -.2179   -.1247   -.1521    .1826    .0338   -.0533   -.3268   -.1876   -.1881   -.4868
102.B1SB3.CO     .0594   -.0213   -.0968   -.1227    .0325    .2708    .1995    .0981   -.2308   -.3308   -.0494   -.4271
103.B1SB3.NX    -.0350   -.0437   -.1065   -.0330   -.2001   -.0360   -.0258    .4294   -.1751   -.0800   -.3273    .0041
                23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
                DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

 18.B3CO        1.0000
 19.B3NX        -.2083   1.0000
 51.ETW         -.1373    .2096   1.0000
 53.ETWSDISP     .1476   -.1790   -.7736   1.0000
 54.ETWSRTHP    -.1754    .1060   -.1195    .3004   1.0000
101.B1SB3.HC    -.2661   -.0954    .1651    .0765    .1239   1.0000
102.B1SB3.CO    -.4796    .0480    .1258   -.0618    .2170    .3636   1.0000
103.B1SB3.NX     .0241   -.5053    .0293    .0443    .0547    .0373    .0575   1.0000
                18.      19.      51.      53.      54.      101.     102.     103.
                B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX

<FINISH>
```

Table 1-12

Active Year 1981
Diesel

```
CORRELATION MATRIX  <2> TAYR:81*FTYP:(8,9)

N= 43  DF= 41  R@ .0500= .3008  R@ .0100= .3887

   VARIABLE

 23.DISP       1.0000
 24.RTHP        .8323   1.0000
  1.FTPHC       .5772    .3246   1.0000
  2.FTPCO       .4681    .5247    .4030   1.0000
  3.FTPNOX      .3706    .4133   -.0112   -.2542   1.0000
 11.B1HC        .1621    .2391    .3519    .4388   -.1383   1.0000
 12.B1CO        .3874    .5326    .2564    .9430   -.2068    .3826   1.0000
 13.B1NX        .4225    .4396   -.0408   -.2172    .9121   -.1937   -.1634   1.0000
 14.B2HC        .1670    .1046    .4320    .3857   -.1276    .7894    .1968   -.1612   1.0000
 15.B2CO        .3766    .4080    .4022    .9706   -.3333    .4670    .8620   -.3156    .4787   1.0000
 16.B2NX        .3413    .3300    .0605   -.2576    .9501   -.1015   -.2362    .7551   -.0853   -.3098   1.0000
 17.B3HC        .5979    .4681    .5228    .4080    .0668    .6457    .2459    .0591    .6931    .3945    .0950   1.0000
 18.B3CO        .6676    .6824    .4690    .9043   -.0529    .3269    .8656    .0199    .2726    .7956   -.0982    .5104
 19.B3NX        .3030    .4641   -.1286   -.2080    .9105   -.1513   -.1254    .9365   -.1583   -.3097    .7468   -.0067
 51.ETW         .8651    .9066    .4055    .5968    .4279    .2588    .6067    .4893    .1389    .4705    .3412    .4559
 53.ETWSDISP  -.8667   -.7425   -.5603   -.3355   -.3422   -.0908   -.2213   -.3786   -.1587   -.2612   -.3355   -.6135
 54.ETWSRTHP  -.5171   -.7642   -.1292   -.2573   -.2252   -.1627   -.2240   -.1839   -.0847   -.2224   -.2028   -.3675
101.B1SB3.HC  -.3820   -.1276   -.1903    .0972   -.1702    .5095    .2147   -.1991    .1749    .1467   -.1697   -.2726
102.B1SB3.CO  -.3793   -.1231   -.2879    .1642   -.2279    .1460    .3502   -.2588   -.1361    .1992   -.2082   -.4341
103.B1SB3.NX   .3886    .0350    .2078   -.0595    .0902   -.1646   -.1310    .2755   -.0582   -.0697    .0846    .1983
              23.      24.      1.       2.       3.       11.      12.      13.      14.      15.      16.      17.
              DISP     RTHP     FTPHC    FTPCO    FTPNOX   B1HC     B1CO     B1NX     B2HC     B2CO     B2NX     B3HC

 18.B3CO       1.0000
 19.B3NX        .0077   1.0000
 51.ETW         .7620    .4578   1.0000
 53.ETWSDISP  -.5542   -.2457   -.7265   1.0000
 54.ETWSRTHP  -.3152   -.2425   -.4359    .5435   1.0000
101.B1SB3.HC  -.1633   -.1254   -.1061    .5006    .0914   1.0000
102.B1SB3.CO  -.1456   -.2027   -.1252    .5134    .0711    .7511   1.0000
103.B1SB3.NX   .0455   -.0728    .1439   -.4326    .0359   -.2610   -.2031   1.0000
              18.      19.      51.      53.      54.      101.     102.     103.
              B3CO     B3NX     ETW      ETWSDISP ETWSRTHP B1SB3.HC B1SB3.CO B1SB3.NX
```

2. Bag 1 CO correlates to the FTP CO better than Bag 3 CO for all cases. The Bag 1 CO correlation coefficients exceed .80 for all cases compared to a minimum Bag 3 CO r of .38. Bag 3 CO appears useful for prediction of FTP emissions for Diesels only.

3. Model year 1981 Diesel vehicles have very good correlation ($r > .90$) of Bag 1 and Bag 3 to the FTP for both CO and NOx emissions. Bag 1 CO and NOx correlation coefficients are slightly greater than the corresponding Bag 3 values.

4. The correlation coefficients for Bag 1 HC vs. FTP HC and Bag 3 HC vs. FTP HC range from .33 to greater than .91. Active year 1981 vehicles equipped with three-way catalysts and/or non-Diesel fuel injected engines appear unique from the other subgroups, having Bag 1 HC vs. FTP HC r values which indicate reasonably good correlation ($r > .91$).

In summary, the correlation coefficients analyzed indicate that accurate prediction of FTP equivalent emissions from test data which don't reflect operation over the cold transient phase is doubtful. However, FTP equivalent emissions can be predicted with reasonable confidence for some individual pollutants and certain specific subgroups of vehicles.

Based on the lack of correlation between Bag 1 emissions and Bag 3 emissions shown in table 1-2 it can be concluded that there is effectively no way to predict Bag 1 emissions, even assuming that one could computer-model-calculate Bag 3 emissions accurately. Even if one further assumes that computer-model-calculated MPG values are accurate, any relationship between predicted emission levels (or emission standards) and MPG based on the use of hot data only is probably worthless.

Appendix 2

Calculation Methodology for Fuel Economy Change Allocation

Appendix 2

Calculation Methodology for Fuel Economy Change Allocation

The procedure for computing fleet fuel economy changes due to specific factors, such as system optimization and weight mix shifts, involves the construction of matched sets of data from a base fleet (e.g. 1978) and a new fleet (e.g. 1979), and calculation of intermediate sales-weighted fleet fuel economy values for the matched sets. Depending on the degree of matching, the data sets being compared include only certain known changes between the sets, and hence the calculated intermediate fleet MPG values reflect the fuel economy effects of only those specific changes in fleet makeup.

CALCULATION OF DIFFERENCES DUE TO SYSTEM OPTIMIZATION: To determine the differences in fuel economy between the 1978 and 1979 cars due to system optimization, it was necessary to limit the comparison to nominally identical vehicles. For each manufacturer it was established which 1978 and 1979 models were identical in terms of weight, displacement, and transmission type. When this was established a new set of sales fractions was calculated, based on 1978 sales estimates, using only those combinations which were carried over from 1978 to 1979. Two sales-weighted fuel economy values (SWMPG) were calculated using the equation below. One calculation using 1978 model MPG values and 1978 carryover sales fractions, and one using the 1979 model MPG values, also with 1978 carryover sales fractions.

$$SWMPG = \frac{1}{\Sigma fi(1/MPG_i)}$$

where fi = sales fraction for stratum i_g whose MPG is MPG_i

The difference between the two values reflects the change in fuel economy due to what we have called system optimization. Since the weights, displacements, transmissions - and their sales distributions - are matched, any difference in fuel economy is due to other factors. The main factors which could be contributing to such a system optimization change in fuel economy are:

- Emission control system design changes;
- Engine design and/or calibration changes;
- Changes in transmission efficiency, shift scheduling, or gear ratios;
- Axle ratio changes;
- Changes in test procedure which influence fuel economy.

DIFFERENCES DUE TO TRANSMISSION MIX SHIFTS: In the analysis of fuel economy changes due to system optimization, any IW/CID/transmission combination not common to both years was eliminated from consideration, and the sales distribution of those combinations that were carried over was held at the 1978 mix. If the calculation is repeated using only weight/displacement combinations as the determinants for model year carryover, those IW/CID/transmission combinations that are not common to both sets of data are not "sifted out", but remain in their respective data bases; also, each of the data bases retains its own sales split between automatics and manuals within the carryover IW/CID combinations.

Again, two SWMPG values are calculated using the same equation, wherein the first MPG_i is the harmonic mean sales-weighted fuel economy of each manufacturer's 1978 models in IW/CID class i, and the second MPG_i is the fuel economy of his 1979 models in IW/CID class i. Both of these SWMPG values are based on the same mix of the IW/CID classes (the 1978 mix), so the difference between the two is due to system optimization plus all changes in transmission mix.

DIFFERENCES DUE TO ENGINE MIX SHIFTS: Similarly, by sifting for carryover at only the weight class level, all differences in the IW/CID structures of the fleets are allowed to remain. The difference between the two SWMPG values calculated on this basis is thus due to system optimization, transmission mix shifts, and shifts in the mix of engine displacements*.

DIFFERENCES DUE TO WEIGHT MIX SHIFTS: The bottom-line SWMPG values calculated from the full, unperturbed data bases, each with its own sales mix, includes all of the above effects plus the effect of non-carryover weight classes and the 1979 redistribution of sales among carryover weight classes.

Table 2-1 summarizes the above calculation methodology, and figure 2-1 shows a diagram of the relationship between the various calculated SWMPG values. Since the methodology is suitable for a comparison between any two vehicle sets (49-States vs. California, cars vs. trucks, manufacturer X vs. Y, etc.), table 2-1 and figure 2-1 are notated for the general case rather than the year-to-year case.

Table 2-2 illustrates the equations for separation of individual factors from the combined effects discussed above.

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*This also includes shifts in the mix of engine standards/systems; Federal vs. California and Spark vs. Diesel.

Table 2 - 1

Method for Constructing Fuel Economy Comparisons between Two Vehicle Groups

Configuration Determinants	Vehicle Group "A"			Vehicle Group "B"			A-to-B SWMPG Change Attributed To:
	MPG Base(mpg_i)	Sales Base(f_i)	Fleet SWMPG	MPG Base(mpg_i)	Sales Base(f_i)	Fleet SWMPG	
IW/CID/Transmission Type	A	A	$FE_{AA}ICT$	B	A	$FE_{BA}ICT$	System optimization in carryover I/C/T combinations
IW/CID	A	A	$FE_{AA}IC$	B	A *	$FE_{BA}IC$	Above plus new/discontinued I/C/T combinations plus shifts in transmission mix within carryover I/C combinations
IW	A	A	$FE_{AA}I$	B	A **	$FE_{BA}I$	Above plus new/discontinued I/C combinations plus shifts in engine mix within carryover IW classes
Open	A	A	FE_{AA}	B	B ***	FE_{BB}	Above plus new/discontinued IW classes plus shifts in IW mix among carryover IW classes

---

* Includes B mix of transmissions within c/o IC classes.

** Includes B mix of CT combinations within c/o weight classes.

*** Includes B mix of all ICT combinations in group B.

Figure 2-1

Relationships between SWMPG Values from Table 2-1

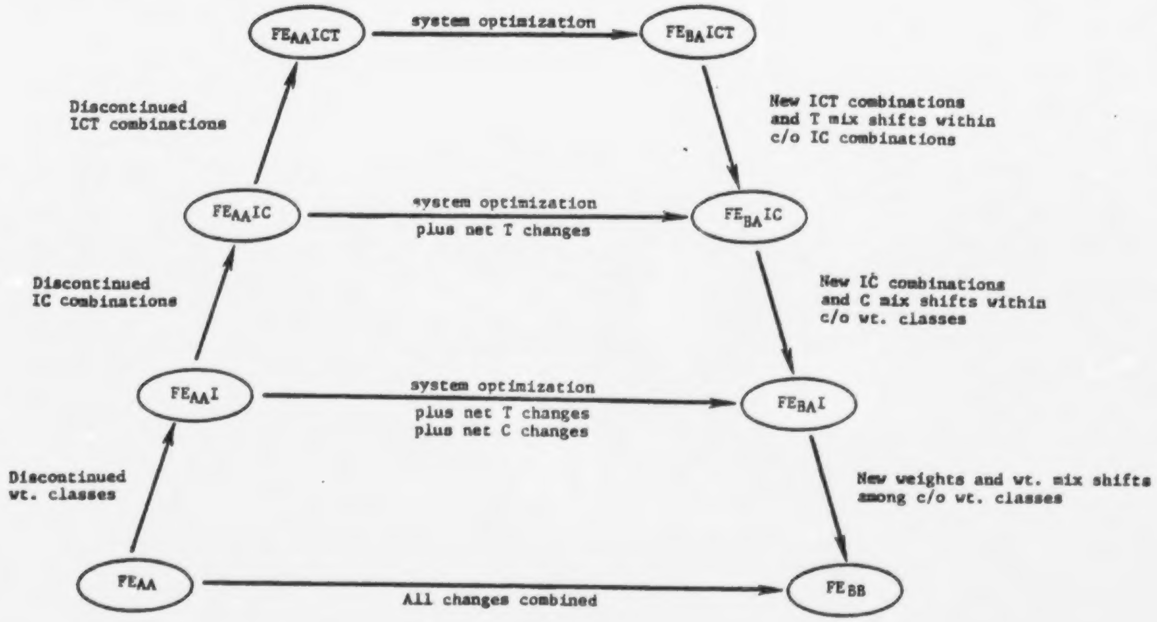

$FE_{AA}ICT$
system optimization
$FE_{BA}ICT$
Discontinued ICT combinations
New ICT combinations and T mix shifts within c/o IC combinations
$FE_{AA}IC$
system optimization plus net T changes
$FE_{BA}IC$
Discontinued IC combinations
New IC combinations and C mix shifts within c/o wt. classes
$FE_{AA}I$
system optimization plus net T changes plus net C changes
$FE_{BA}I$
Discontinued wt. classes
New weights and wt. mix shifts among c/o wt. classes
FE_{AA}
All changes combined
FE_{BB}

Table 2 - 2

Isolation of Specific Factors Causing Fuel Economy Change

Percent Change in Fuel Economy Due To:	**Calculated By:**
Systems Optimization	$\left[\left(\frac{FE_{BA}ICT}{FE_{AA}ICT}\right) - 1\right] \times 100$
Transmission Mix Shifts	$\left[\left(\frac{FE_{BA}IC}{FE_{AA}IC} \div \frac{FE_{BA}ICT}{FE_{AA}ICT}\right) - 1\right] \times 100$
Engine Mix Shifts	$\left[\left(\frac{FE_{BA}I}{FE_{AA}I} \div \frac{FE_{BA}IC}{FE_{AA}IC}\right) - 1\right] \times 100$
Weight Mix Shifts	$\left[\left(\frac{FE_{BB}}{FE_{AA}} \div \frac{FE_{BA}I}{FE_{AA}I}\right) - 1\right] \times 100$
All Changes Combined	$\left[\left(\frac{FE_{BB}}{FE_{AA}}\right) - 1\right] \times 100$

Appendix 3

Variability Estimates for Emissions and Economy over the FTP

To Karl Hellman 25 March, 1981
From John Foster
Re Test to test variability

Using similar procedure and the same data as my sensitivity study (see my memo to you of 12 March), I have looked into the differences between multiple tests on the same vehicles.

For each multiply-tested car I calculated the mean fuel economy, HC, CO, and NOx, for both city and highway test cycles. I also found the standard deviations of these 8 means, which are measures of their test-to-test variability. The 1027 vehicles were then averaged to find their mean standard deviation. Here are the results:

		DIFFERENCE			(AVERAGE)
VARIABLE	N	MINIMUM	MAXIMUM	MEAN	STD DEV
1.FECITY	1027	0.	3.5360	.46217	.49646
2.HCCITY	1027	0.	1.7480	.066068	.10265
3.COCITY	1027	0.	54.477	1.0577	2.0976
4.NOXCITY	1027	0.	1.2800	.12346	.13782
5.FEHWY	432	0.	7.5660	1.0039	1.0633
6.HCHWY	430	0.	.43500	.015156	.029851
7.COHWY	361	0.	11.709	.33817	.88500
8.NOXHWY	431	0.	1.6720	.18613	.22276

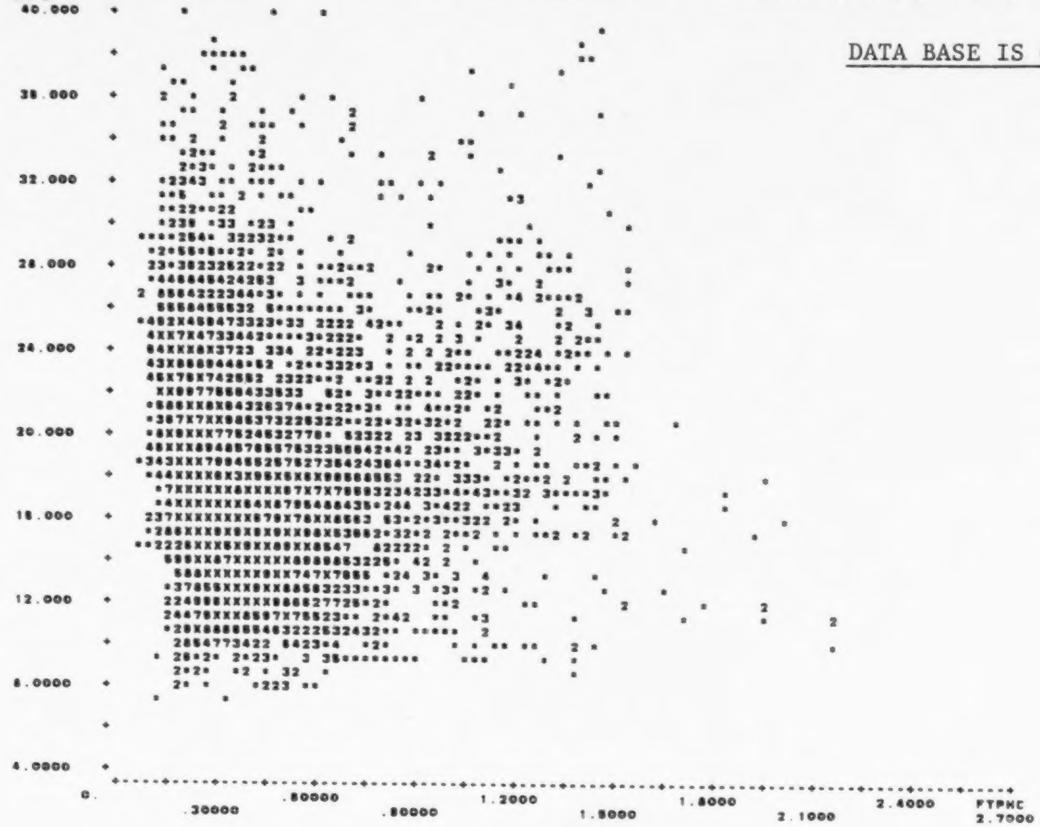
Data base is CERT/EPA for model years 1975 to 1982.

Appendix 4

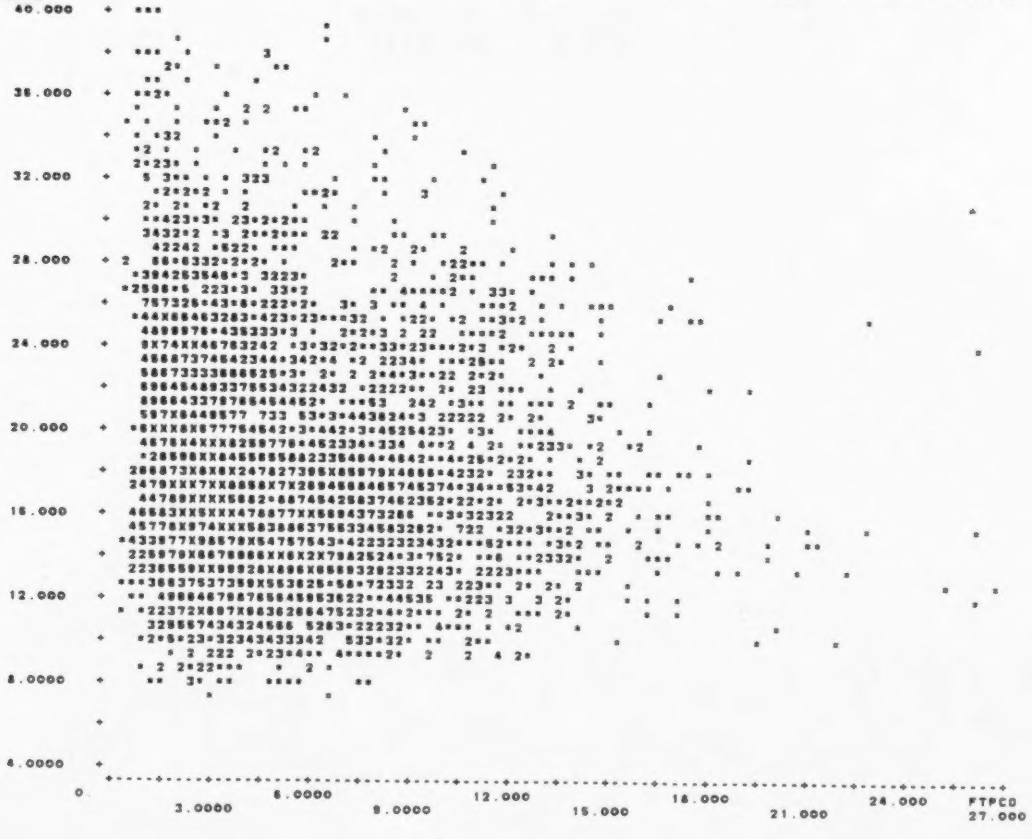
Two Variable Linear Regression Plots of Emissions versus Economy (Data from all Model Years Available and No Stratification of the Data)

(SCATTER VAR=11;1 CASES=ALL INTERVAL=(4.,40);(0,2.7))-SCATTER PLOT   N= 4551 OUT OF 5753 11.UMPG VS. 1.FTPHC

DATA BASE IS CERT/EPA

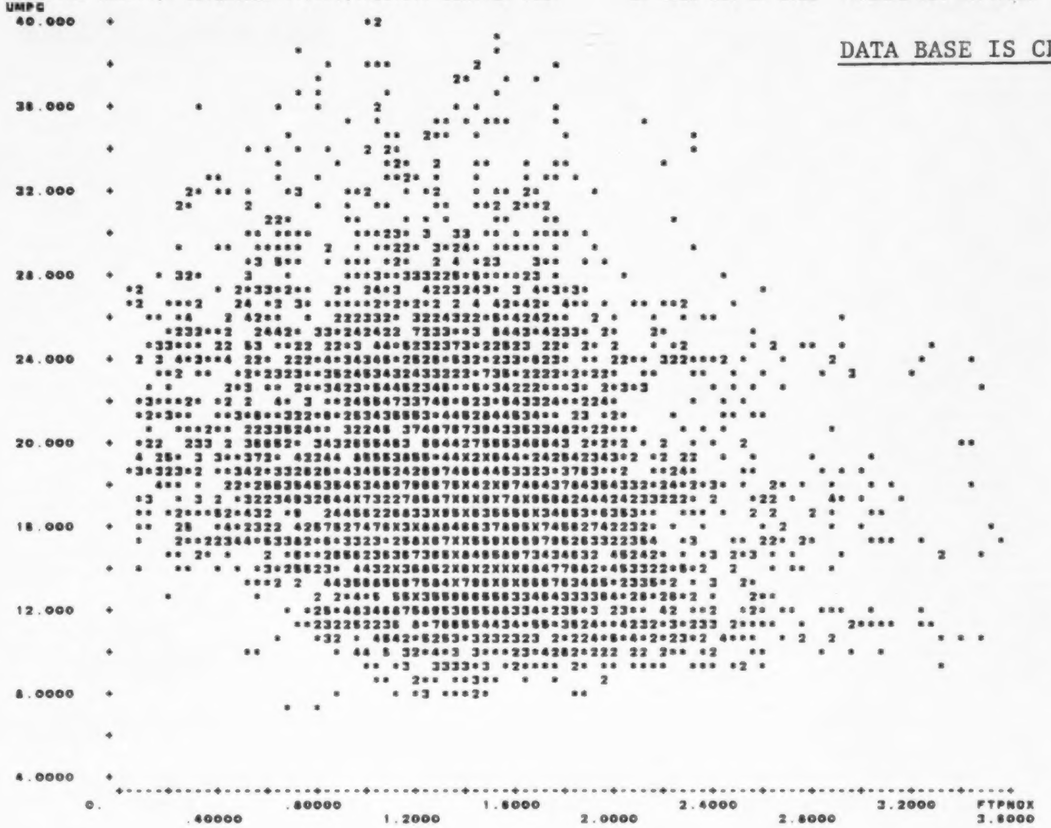


(SCATTER VAR=11;2 INTERVAL=(4.,40);(0,27))-SCATTER PLOT   N= 4568 OUT OF 5753 11.UMPG VS. 2.FTPCO

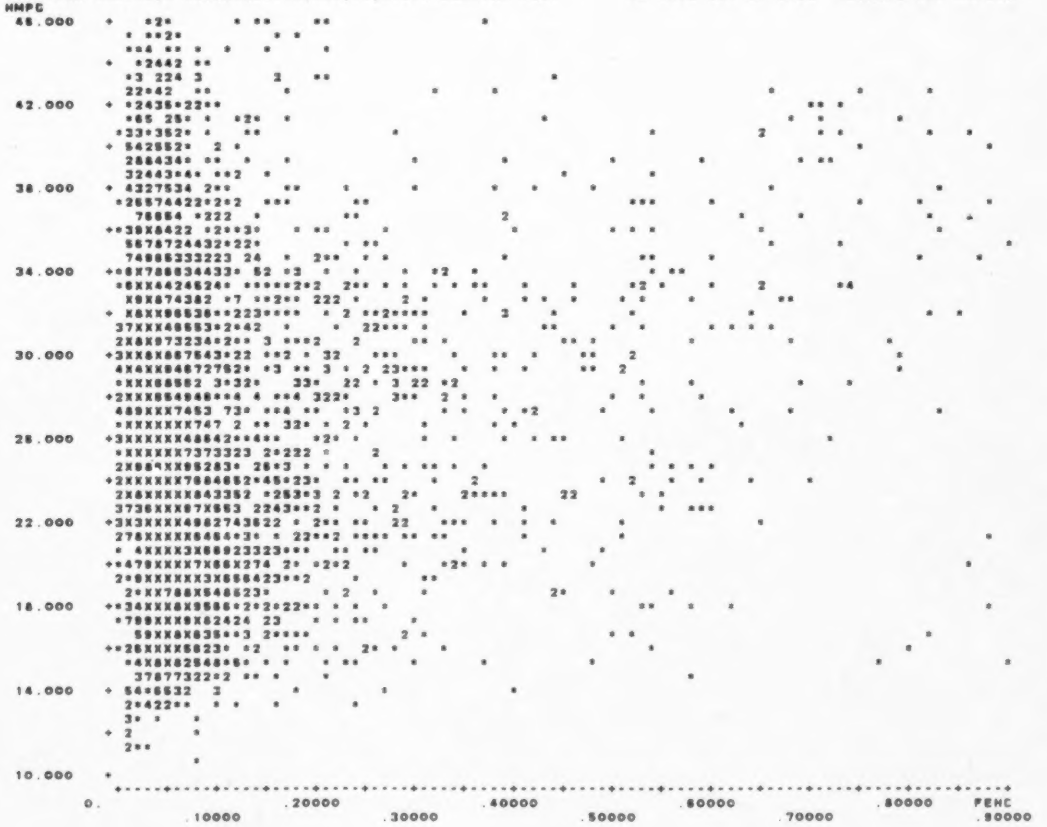


<SCATTER VAR=11;3 INTERVAL=(4.,40);(0,3.6)>-SCATTER PLOT N= 4582 OUT OF 5783 11.UMPG VS. 3.FTPNOX

DATA BASE IS CERT/EPA

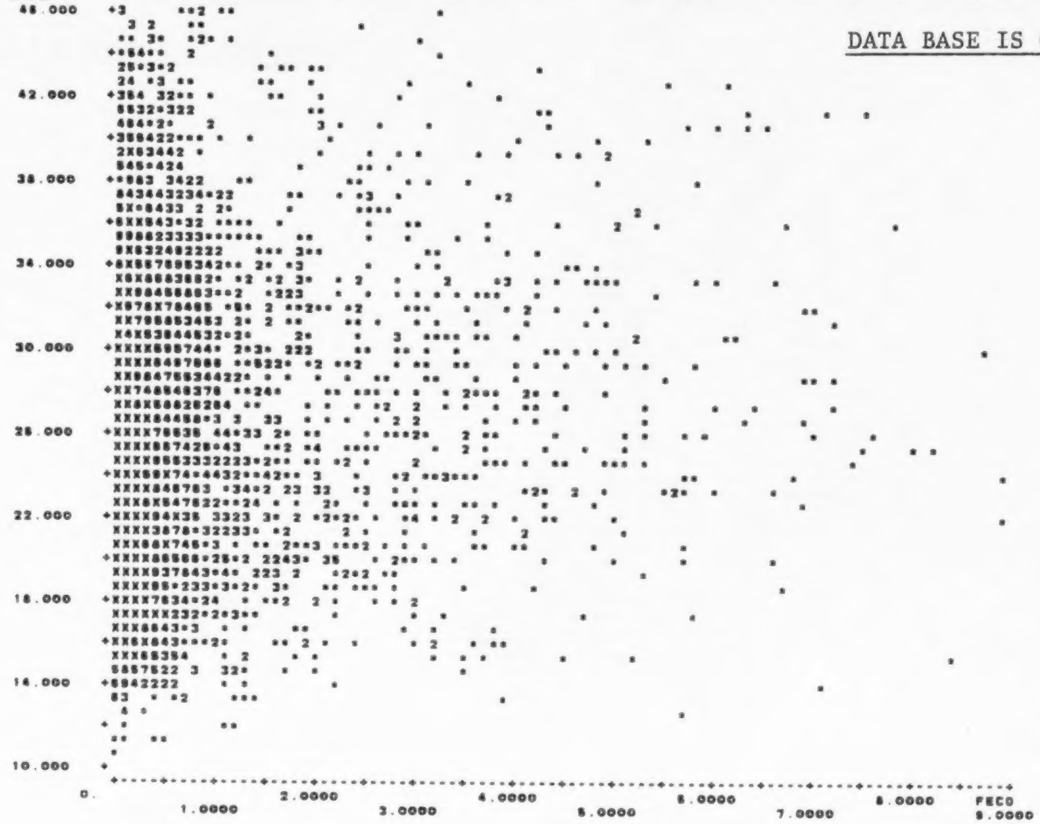


<SCATTER VAR=12;4 INTERVAL=(10,46);(0,0.9)>-SCATTER PLOT N= 4012 OUT OF 5783 12.HMPG VS. 4.FEHC

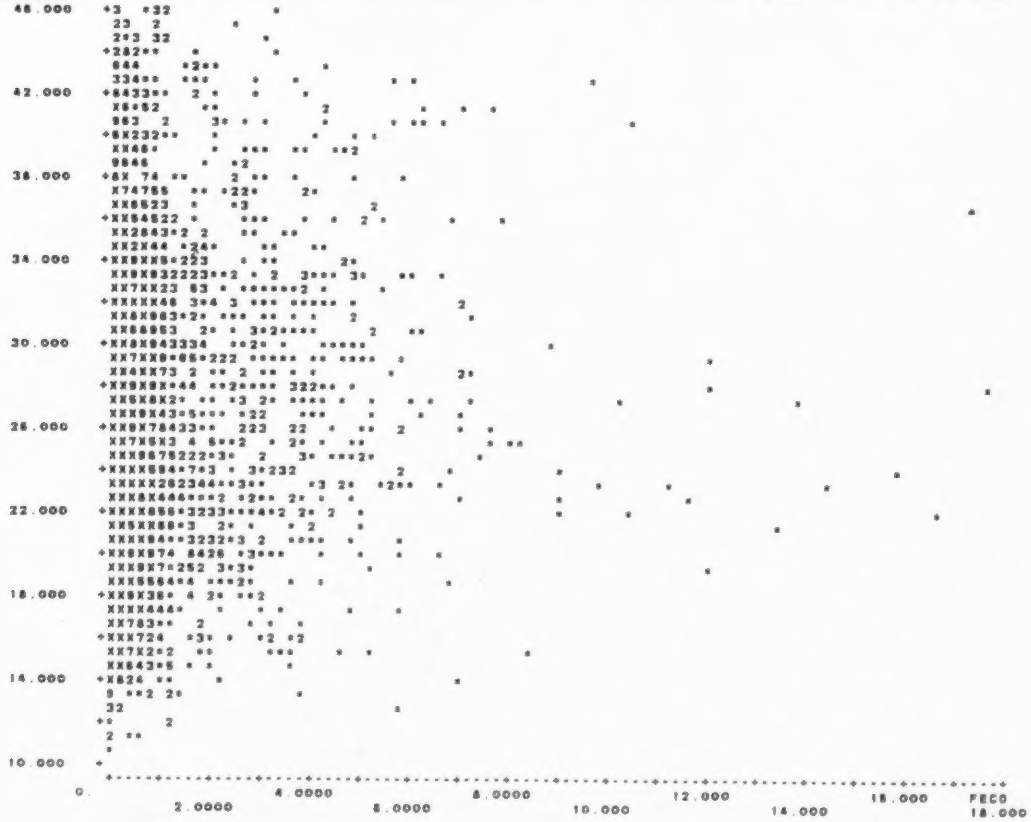


DATA BASE IS CERT/EPA

```
<SCATTER VAR=12;5 INTERVAL=(10,46);(0,9.)>-SCATTER PLOT        N= 4028 OUT OF 5753  12.HMPG VS. 5.FECO
```

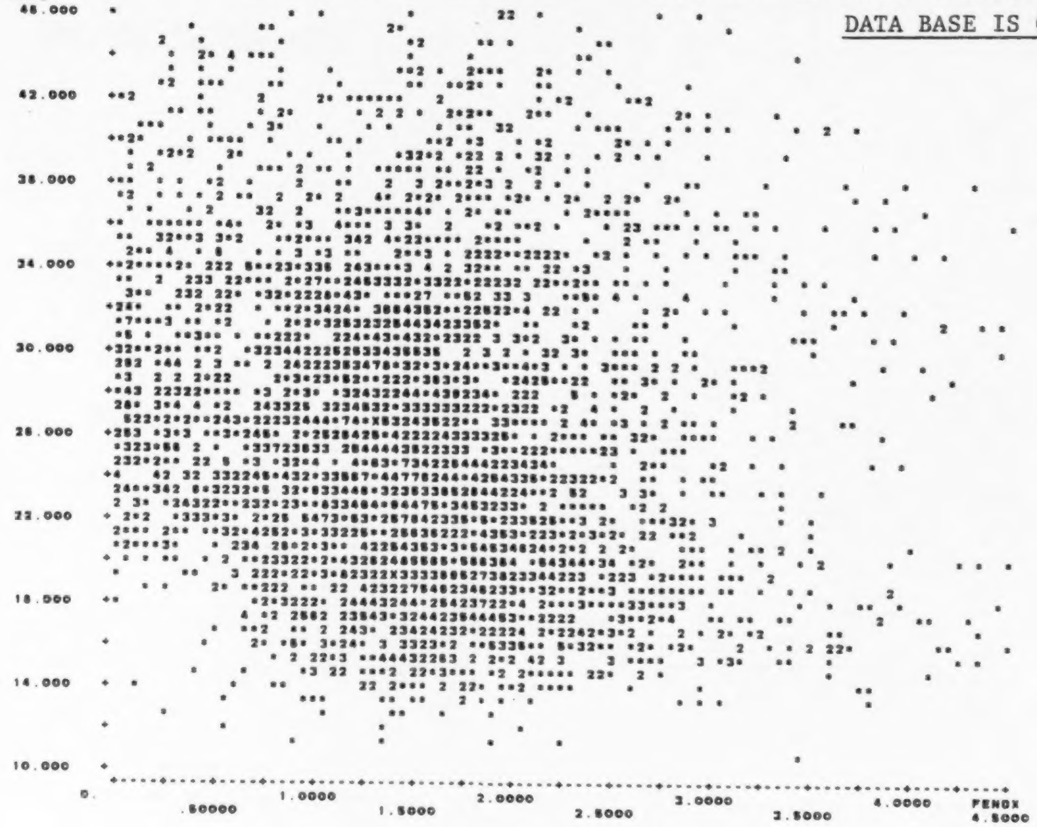


```
<SCATTER VAR=12;5 INTERVAL=(10,46);(0,18)>-SCATTER PLOT        N= 4045 OUT OF 5753  12.HMPG VS. 5.FECO
```

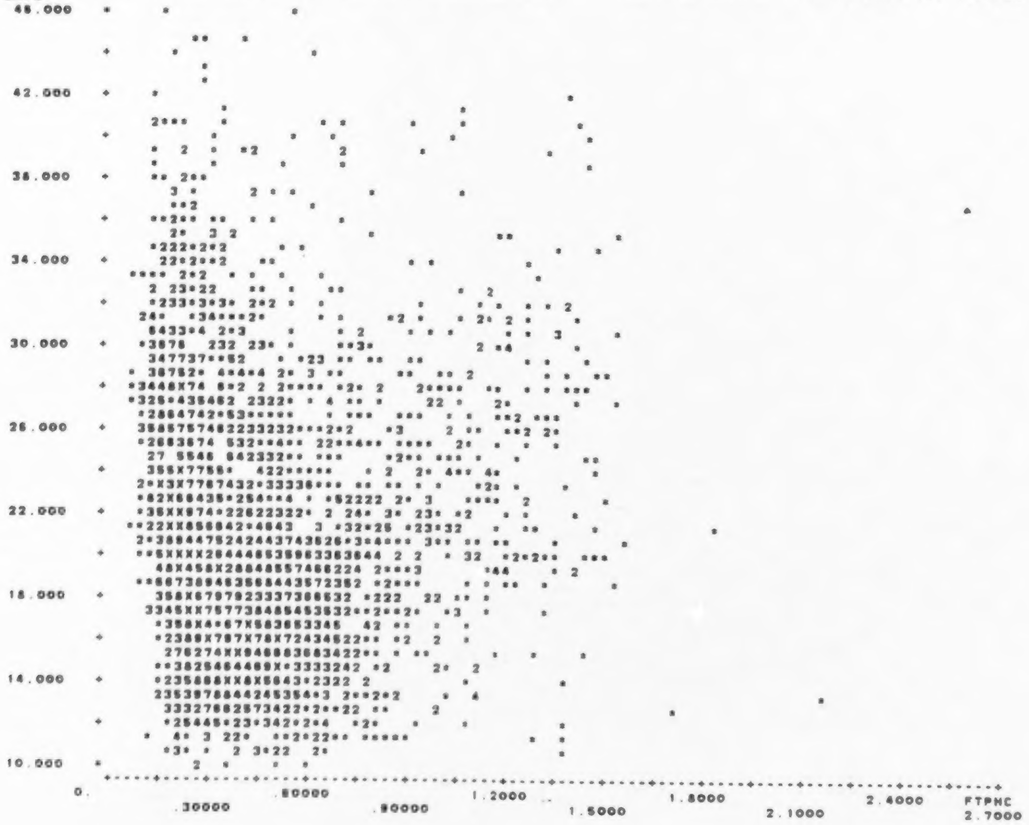


<SCATTER VAR=12;8 INTERVAL=(10,46);(0,4.5)>-SCATTER PLOT N= 4038 OUT OF 5783 12.HMPG VS. 8.FENOX

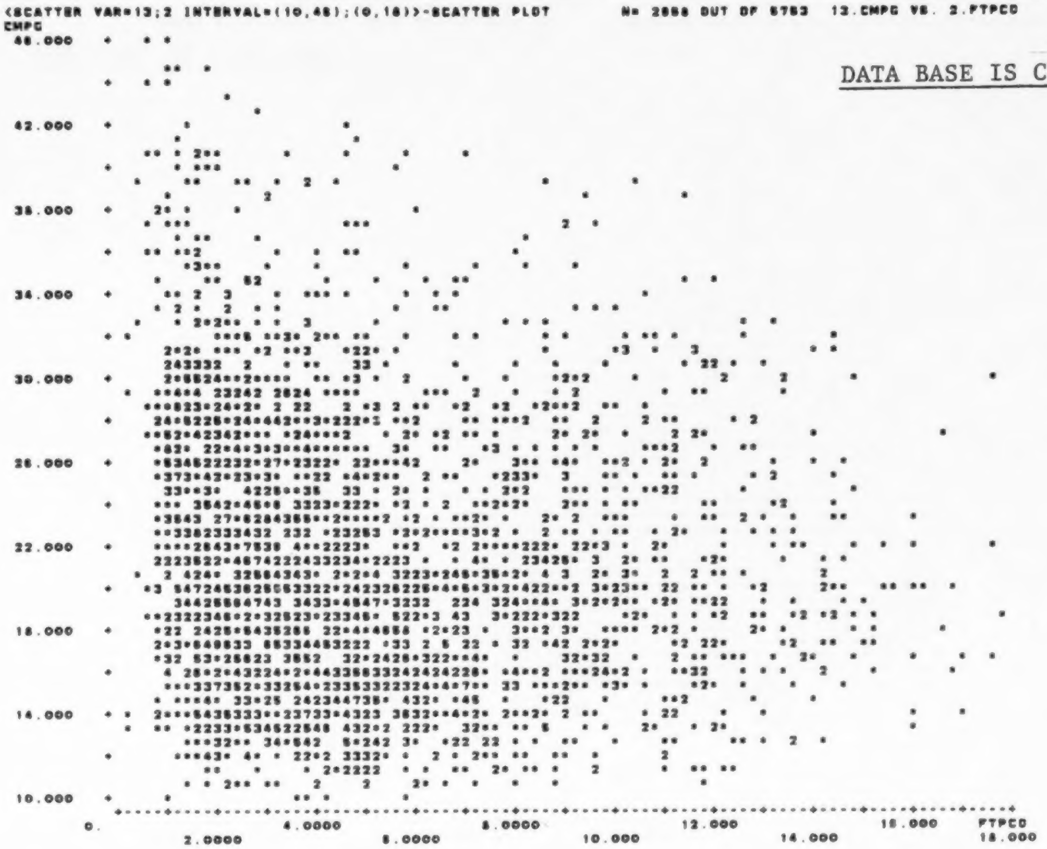
DATA BASE IS CERT/EPA



<SCATTER VAR=13;1 INTERVAL=(10,46);(0,2.7)>-SCATTER PLOT N= 2985 OUT OF 5783 13.CMPG VS. 1.FTPHC



DATA BASE IS CERT/EPA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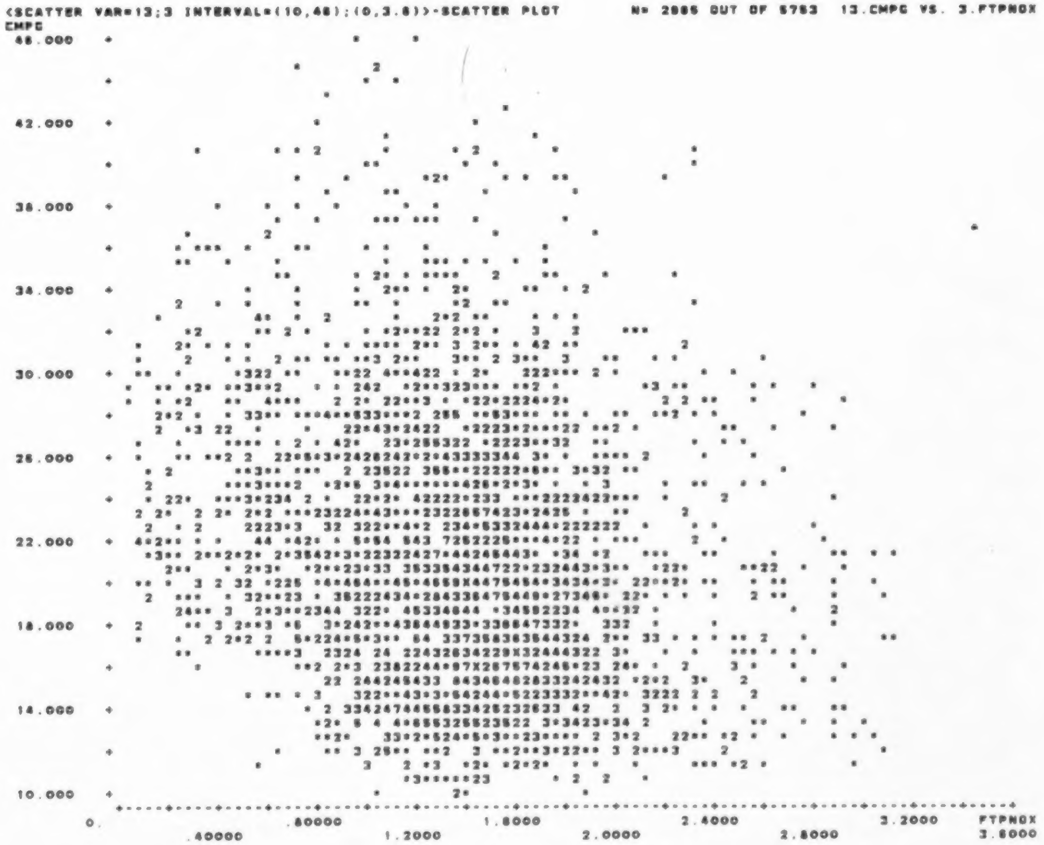
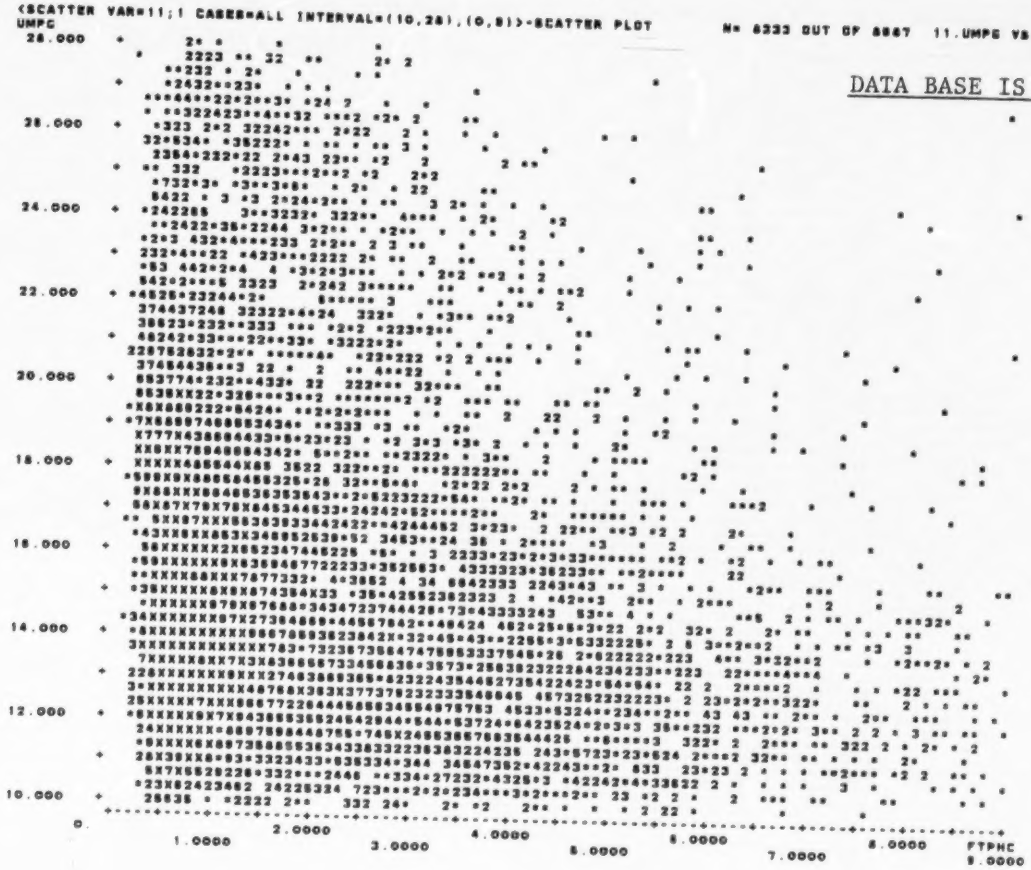
<SCATTER VAR=13;2 INTERVAL=(10,46);(0,18)>-SCATTER PLOT       N= 2888 OUT OF 5753  13.CMPG VS. 2.FTPCO
```

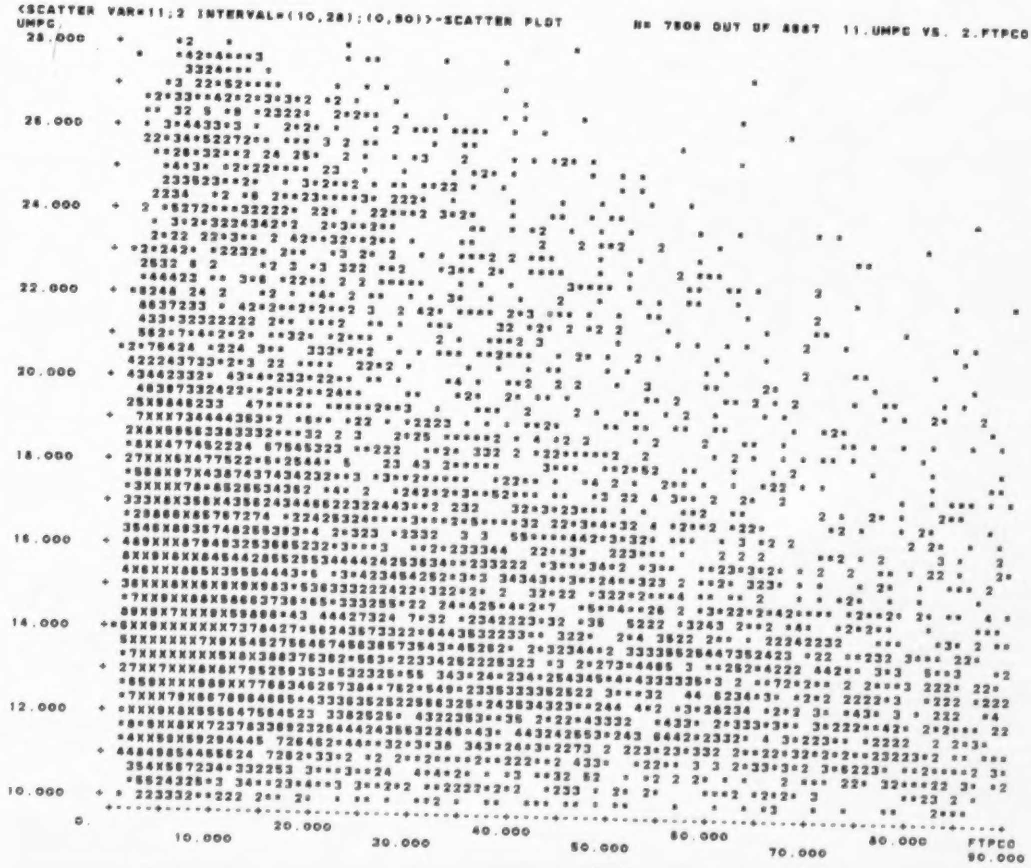

```
<SCATTER VAR=13;3 INTERVAL=(10,46);(0,3.6)>-SCATTER PLOT       N= 2885 OUT OF 5753  13.CMPG VS. 3.FTPNOX
```

```
<SCATTER VAR=11;1 CASES=ALL INTERVAL=(10,28),(0,9)>-SCATTER PLOT      N= 8333 OUT OF 8887  11.UMPG VS. 1.FTPHC
```

DATA BASE IS EF

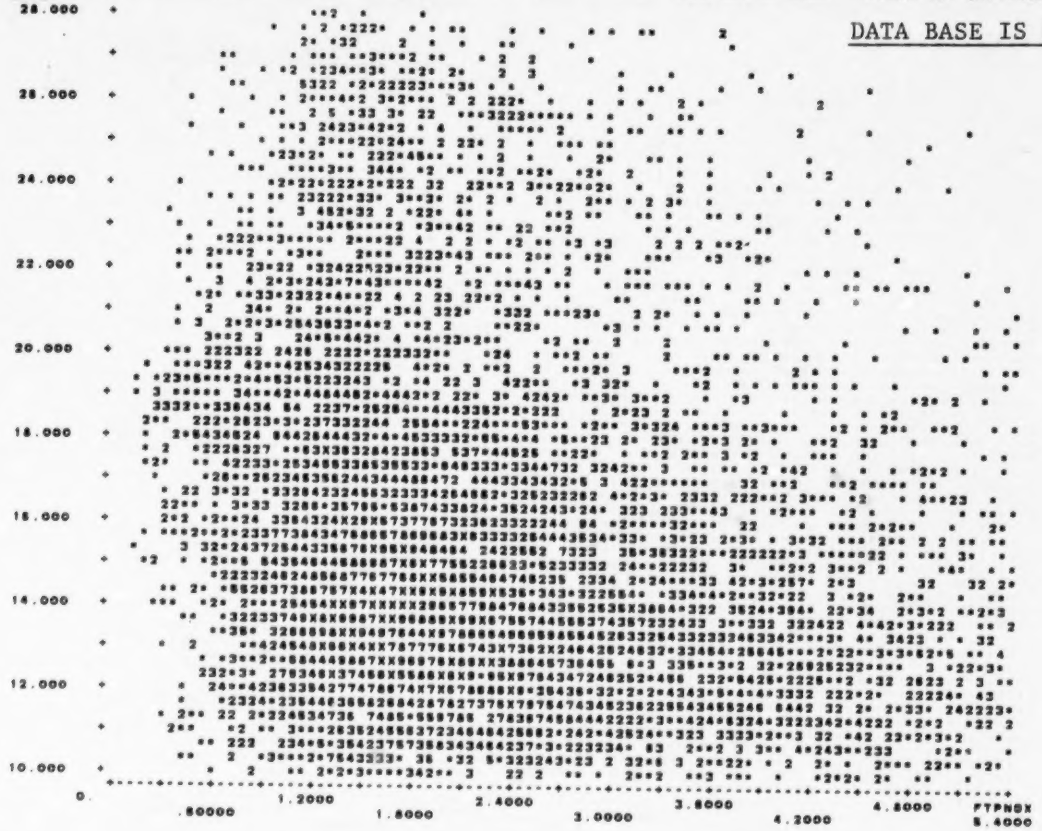


```
<SCATTER VAR=11;2 INTERVAL=(10,28);(0,90)>-SCATTER PLOT      N= 7808 OUT OF 8887  11.UMPG VS. 2.FTPCO
```

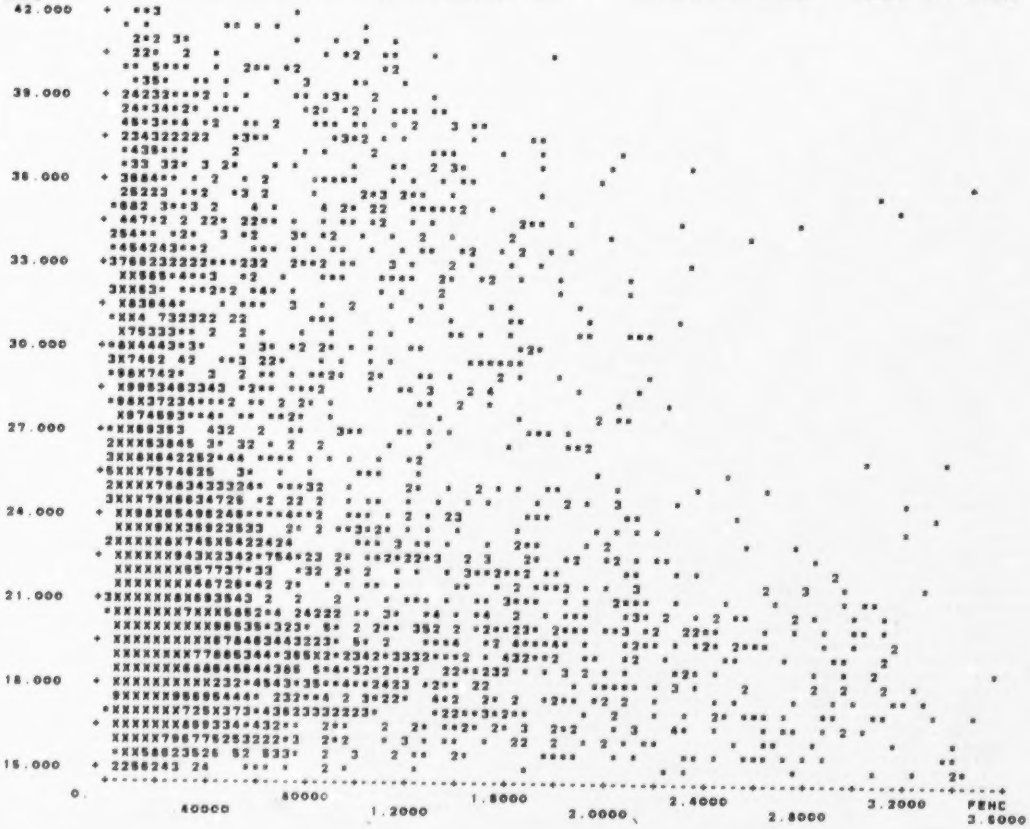


DATA BASE IS EF

<SCATTER VAR=11;3 INTERVAL=(10,28);(0,5.4)>-SCATTER PLOT N= 7843 OUT OF 8887 11.UMPG VS. 3.FTPNOX

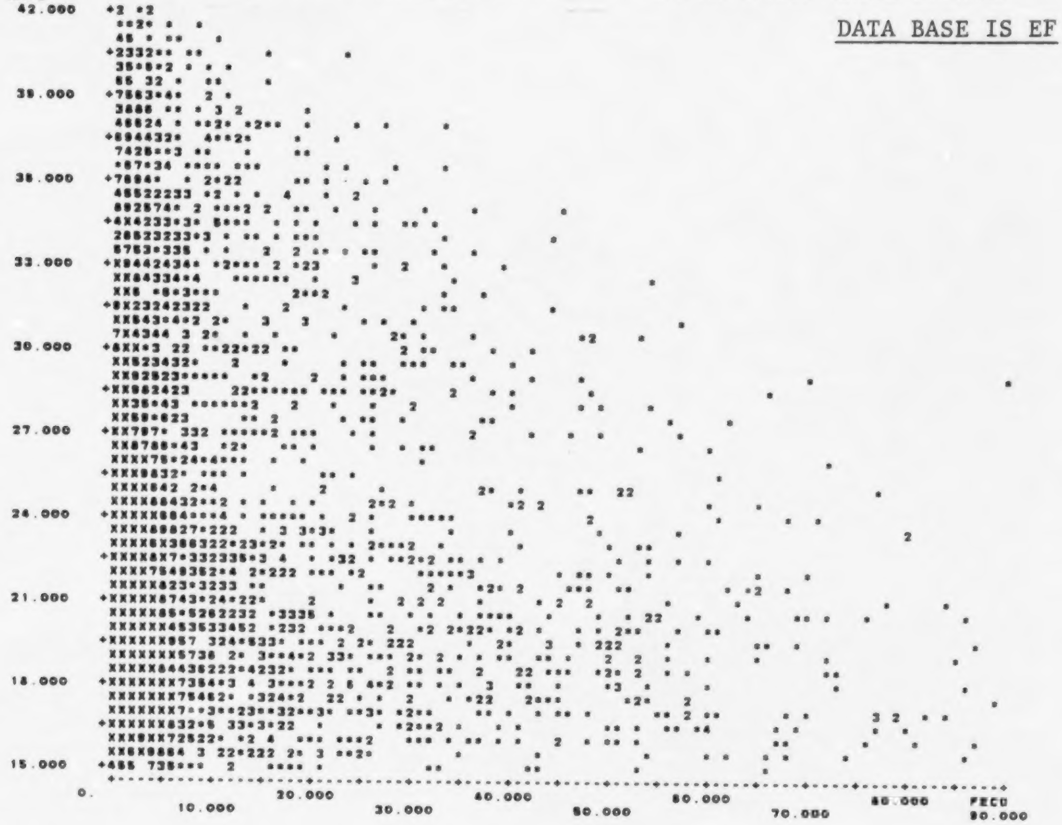


<SCATTER VAR=12;4 INTERVAL=(15,42);(0,3.6)>-SCATTER PLOT N= 8214 OUT OF 8887 12.HMPG VS. 4.FEHC

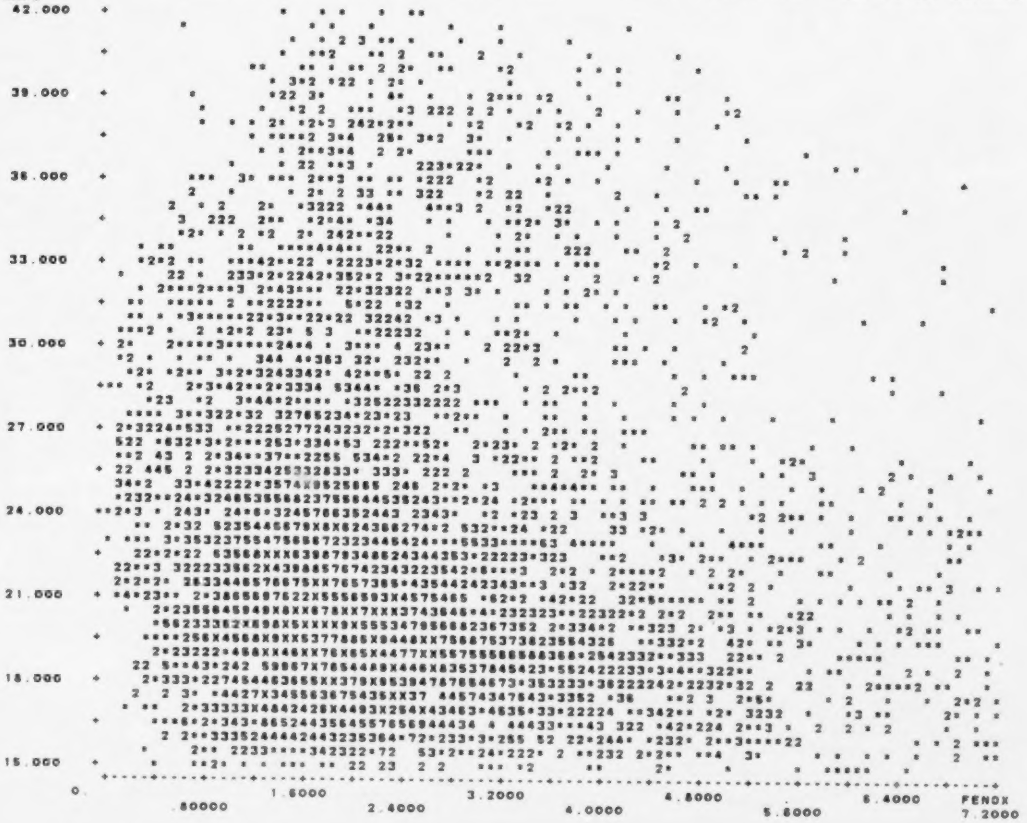


DATA BASE IS EF

```
<SCATTER VAR=12;5 INTERVAL=(15,42);(0,90)>-SCATTER PLOT        N= 5980 OUT OF 6987  12.HMPG VS. 5.FECO
```

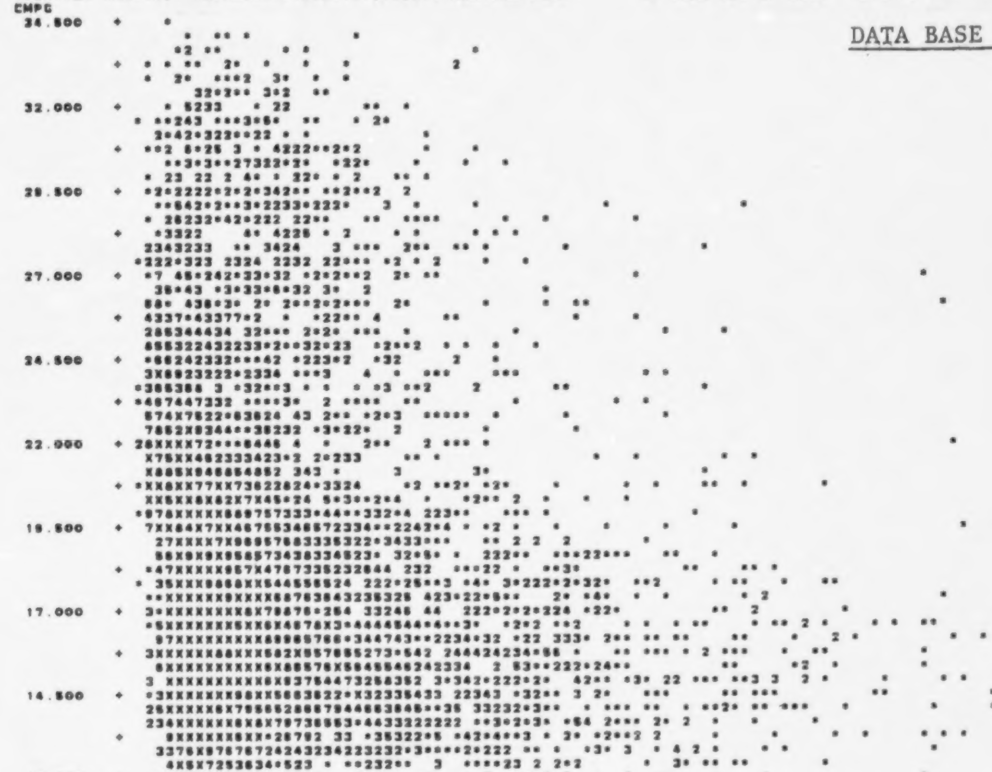


```
<SCATTER VAR=12;6 INTERVAL=(15,42);(0,7.2)>-SCATTER PLOT        N= 6077 OUT OF 6987  12.HMPG VS. 6.FENOX
```

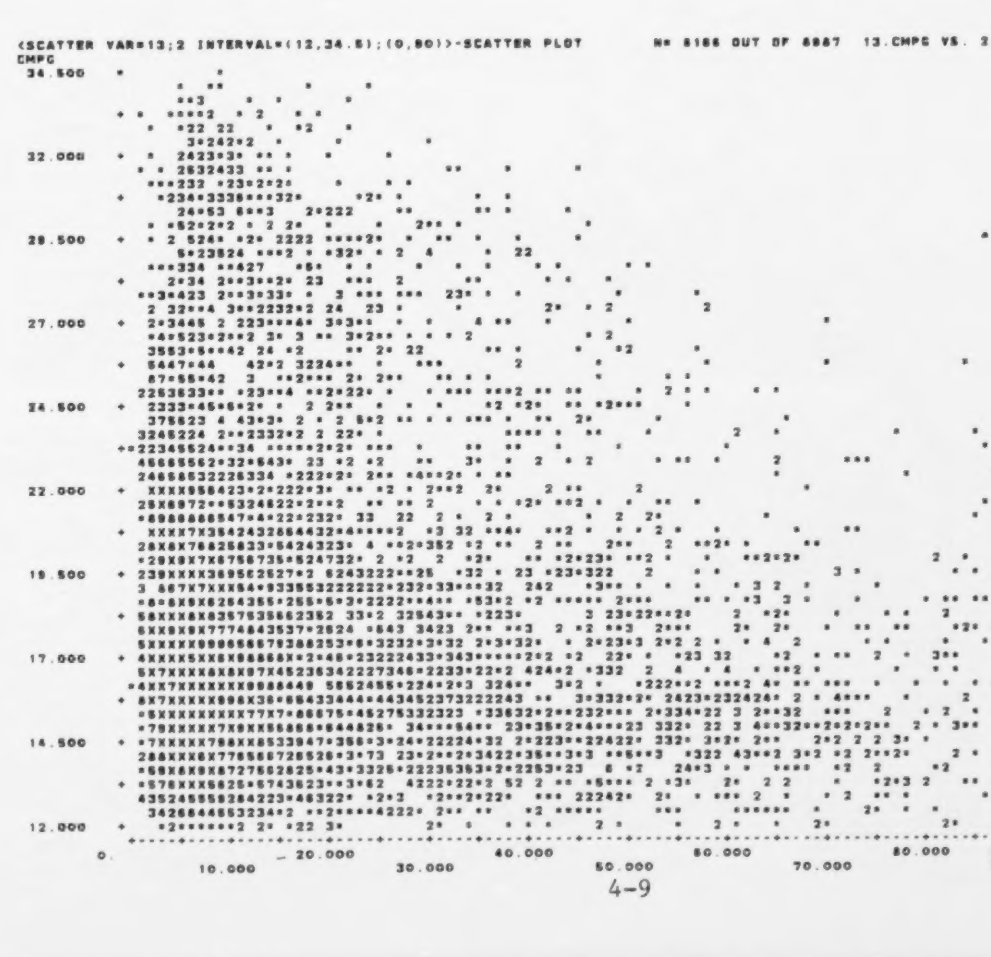


```
<SCATTER VAR=13;1 INTERVAL=(12,34.5);(0,9)>-SCATTER PLOT        N= 8322 OUT OF 8887  13.CMPG VS. 1.FTPHC
```

DATA BASE IS EF

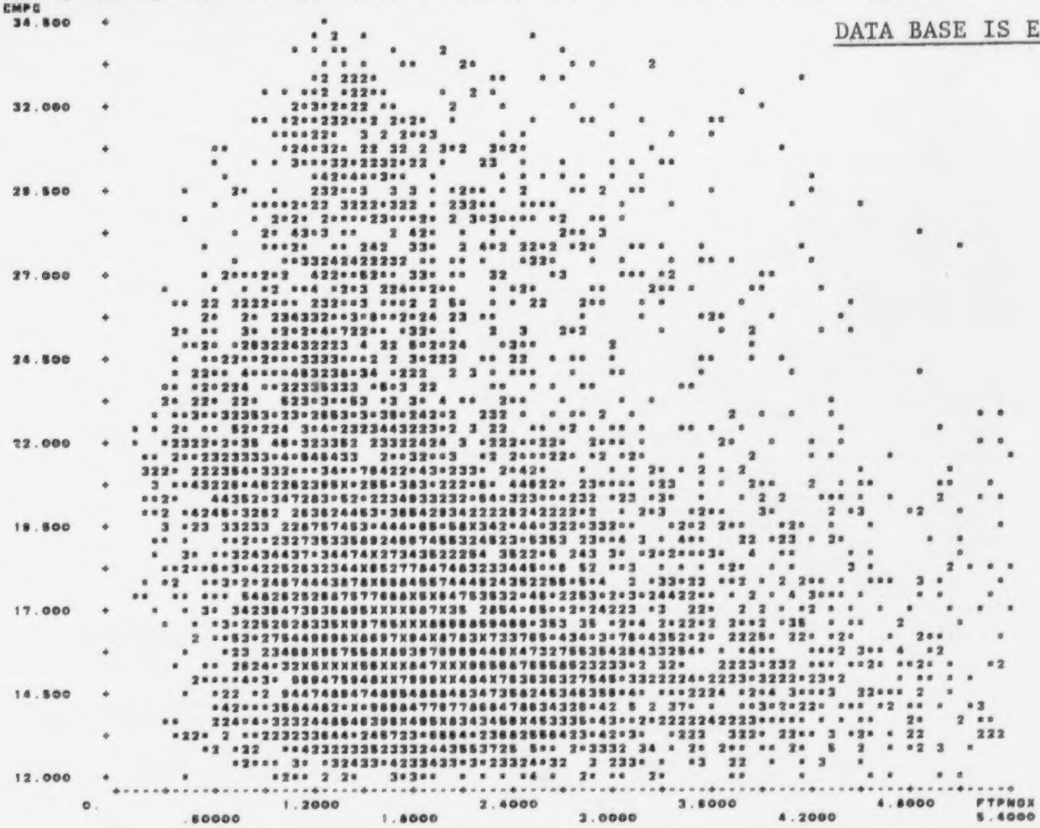


```
<SCATTER VAR=13;2 INTERVAL=(12,34.5);(0,90)>-SCATTER PLOT        N= 8186 OUT OF 8887  13.CMPG VS. 2.FTPCO
```



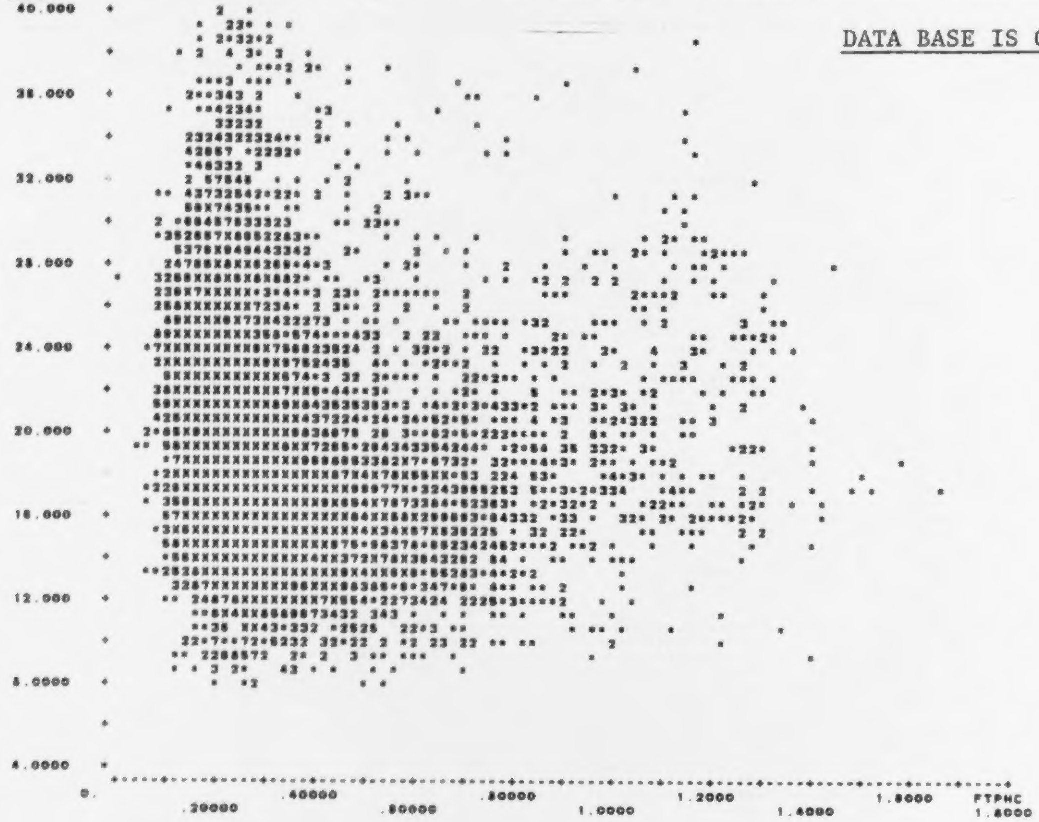
```
<SCATTER VAR=13;3 INTERVAL=(12,34.5);(0,5.4))-SCATTER PLOT        N= 8083 OUT OF 8887  13.CMPG VS. 3.FTPNOX
```

DATA BASE IS EF

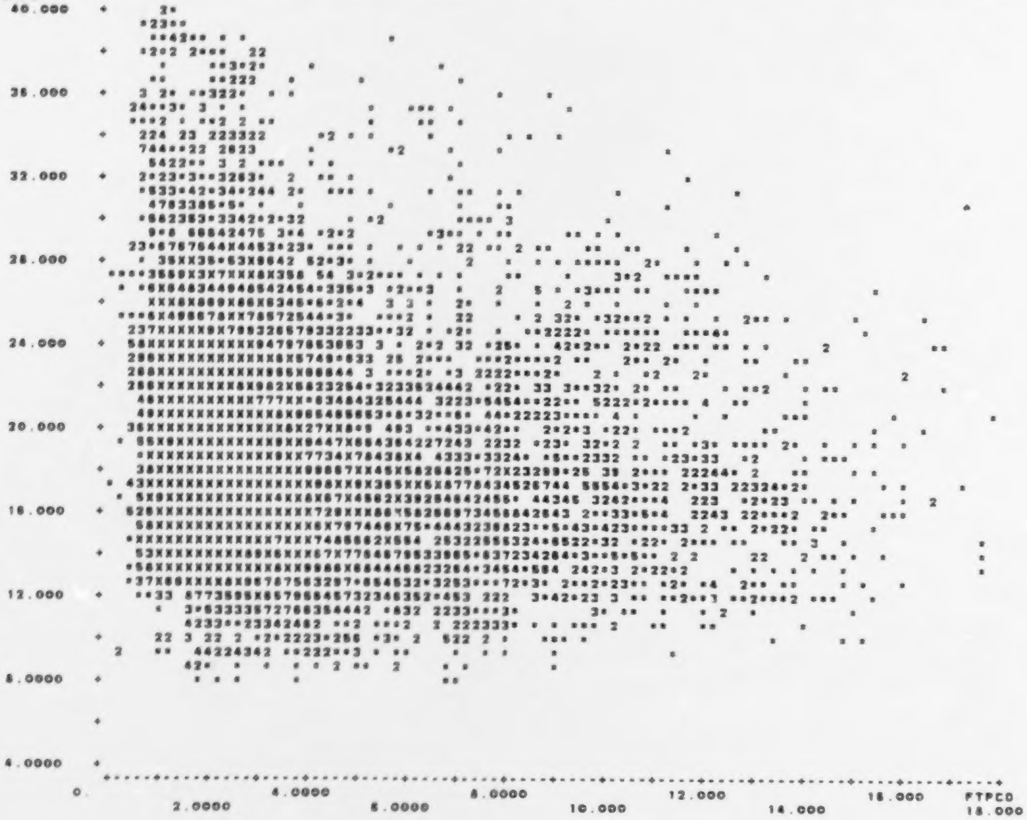


DATA BASE IS CERT/MFR

<SCATTER VAR=11;1 CASES=ALL INTERVAL=(4.,40);(0,1.8)>-SCATTER PLOT   N= 7782 OUT OF 10425 11.UMPG VS. 1.FTPHC

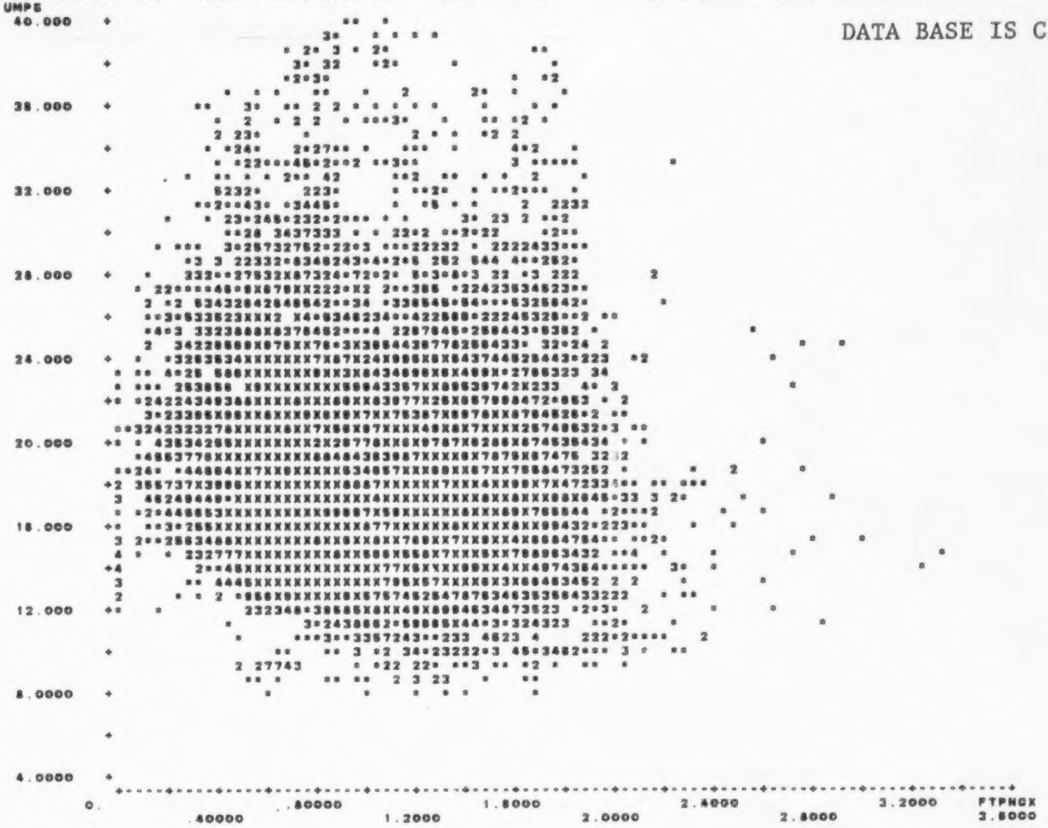


<SCATTER VAR=11;2 INTERVAL=(4.,40);(0,18)>-SCATTER PLOT   N= 9738 OUT OF 10425 11.UMPG VS. 2.FTPCD

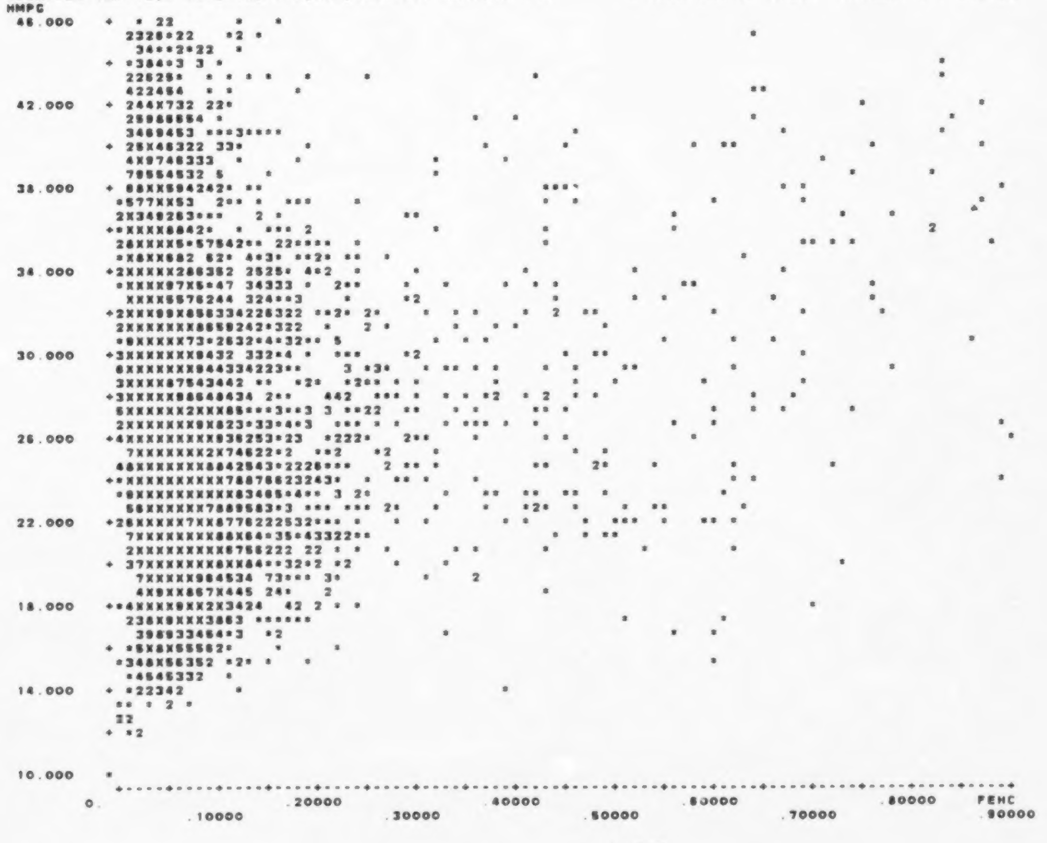


DATA BASE IS CERT/MFR

<SCATTER VAR=11;3 INTERVAL=(4.,40);(0,3.8))-SCATTER PLOT   N= 9782 OUT OF 10426 11.UMPG VS. 3.FTPNOX

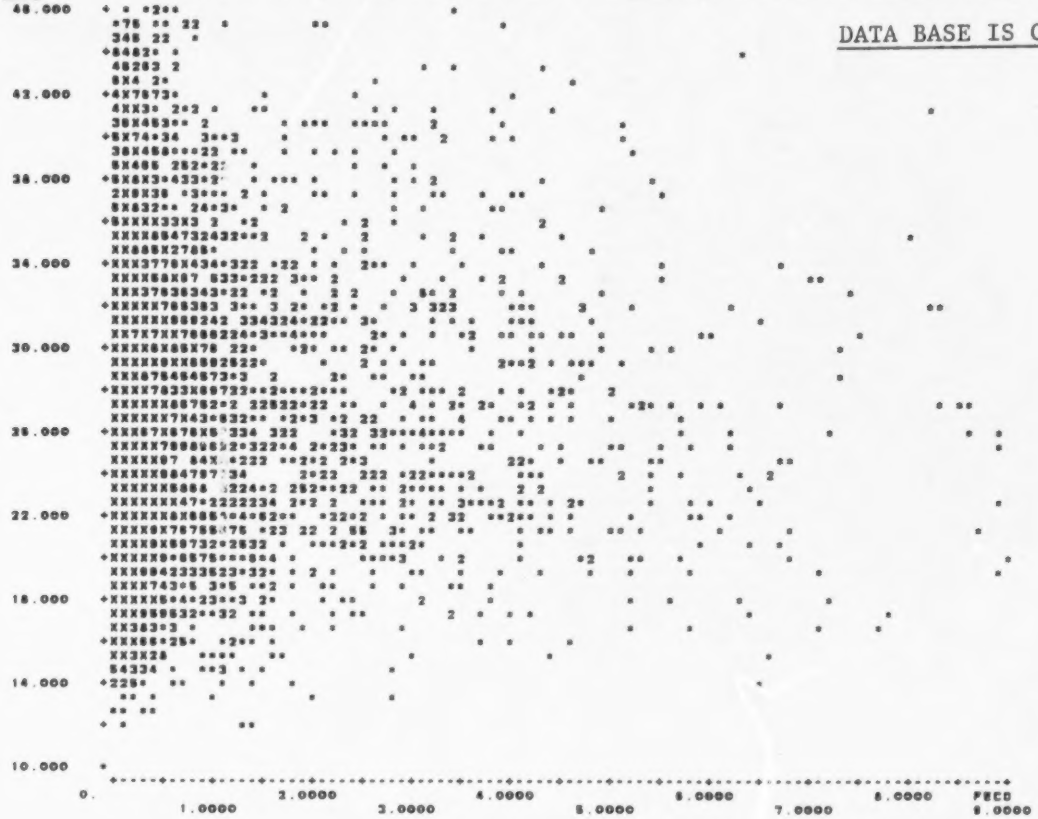


<SCATTER VAR=12;4 INTERVAL=(10,46);(0,0.9))-SCATTER PLOT   N= 5606 OUT OF 10426 12.HMPG VS. 4.FEHC

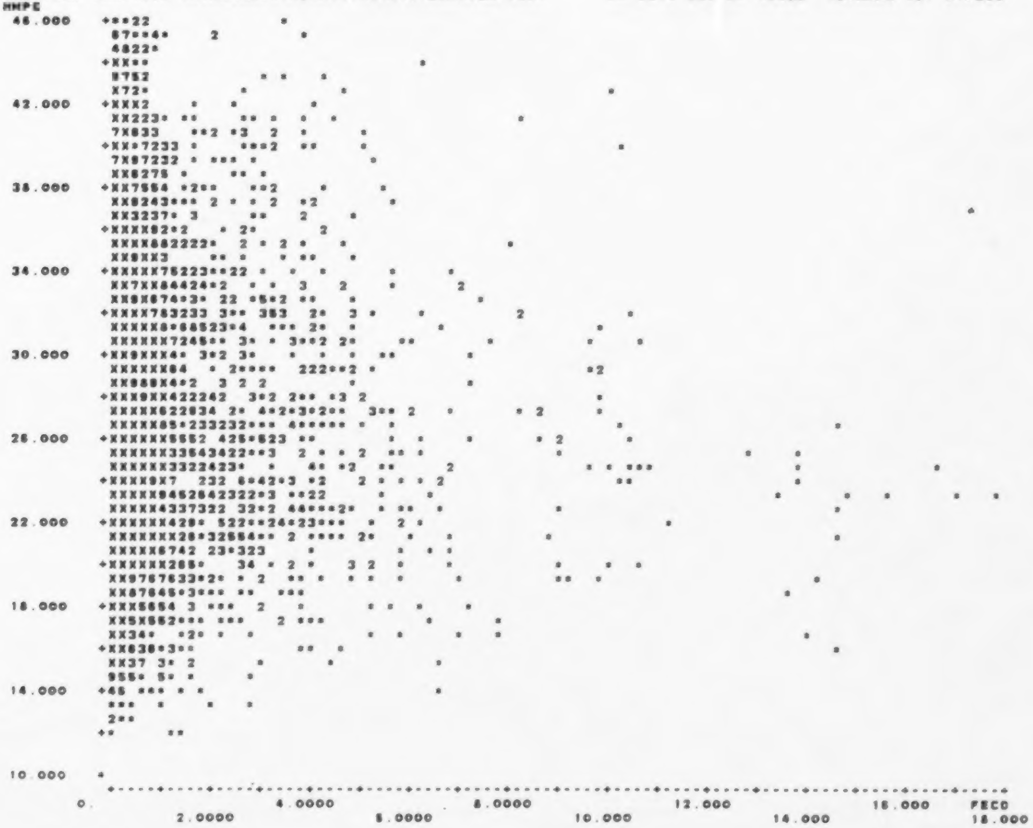


```
<SCATTER VAR=12;5 INTERVAL=(10,46);(0,9.)>-SCATTER PLOT      N= 5574 OUT OF 10425  12.HMPG VS. 5.FECD
```

DATA BASE IS CERT/MFR

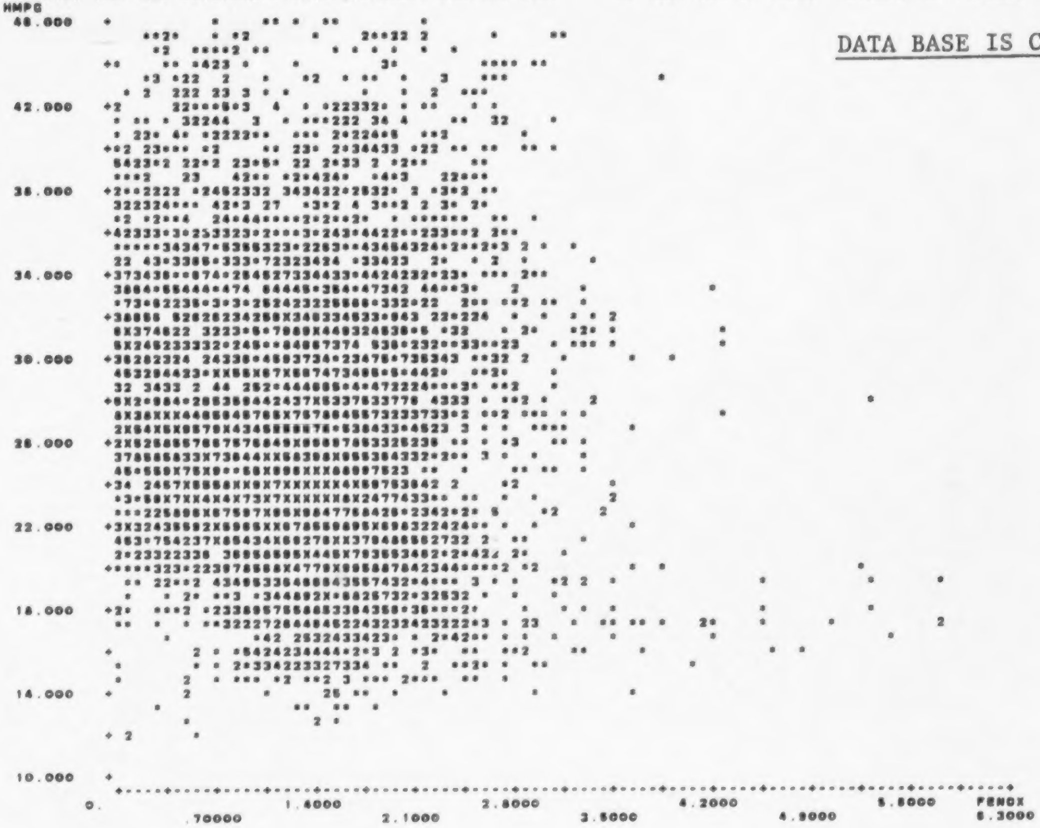


```
<SCATTER VAR=12;5 INTERVAL=(10,46);(0,18)>-SCATTER PLOT      N= 5817 OUT OF 10425  12.HMPG VS. 5.FECD
```

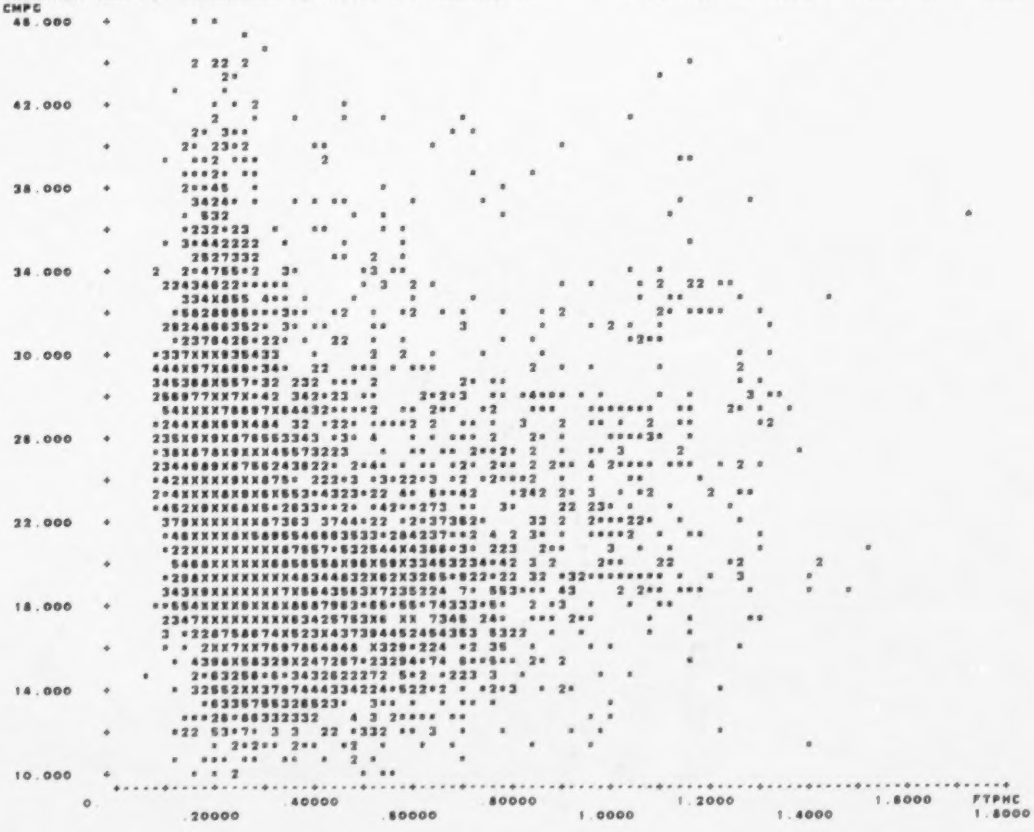


```
<SCATTER VAR=12;8 INTERVAL=(10,46);(0,6.3))-SCATTER PLOT      N= 5821 OUT OF 10425  12.HMPG VS. 8.FENOX
```

DATA BASE IS CERT/MFR

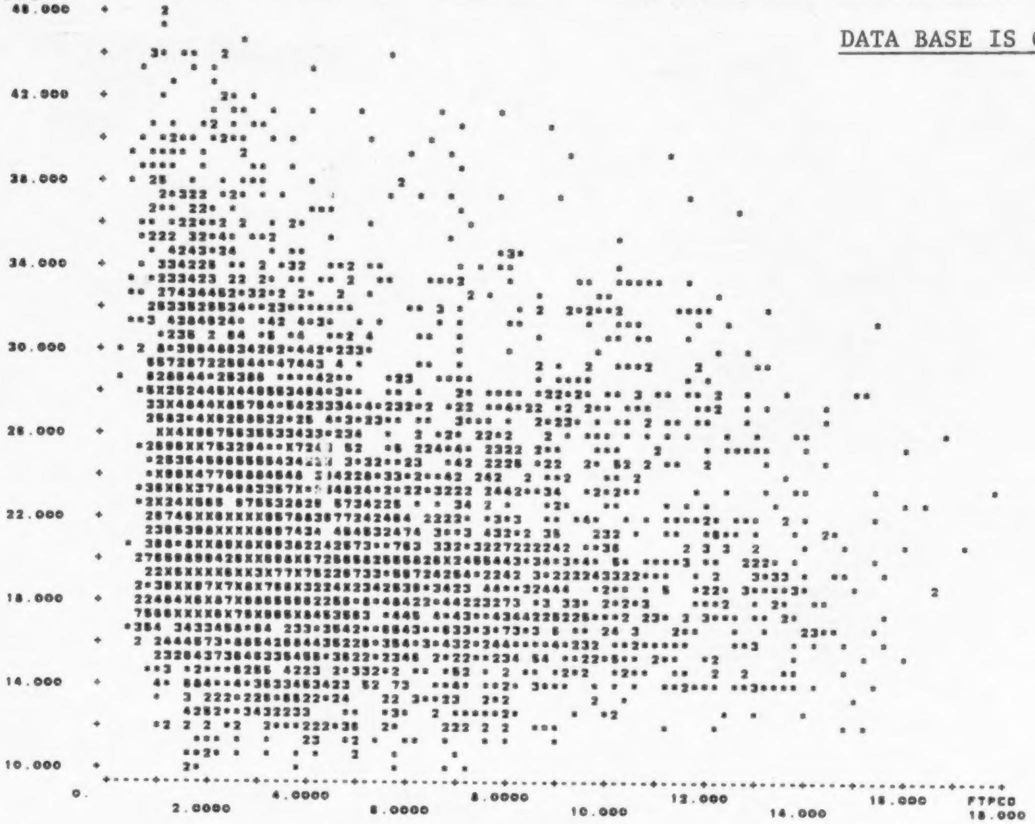


```
<SCATTER VAR=13;1 INTERVAL=(10,46);(0,1.8))-SCATTER PLOT      N= 5071 OUT OF 10425  13.CMPG VS. 1.FTPHC
```

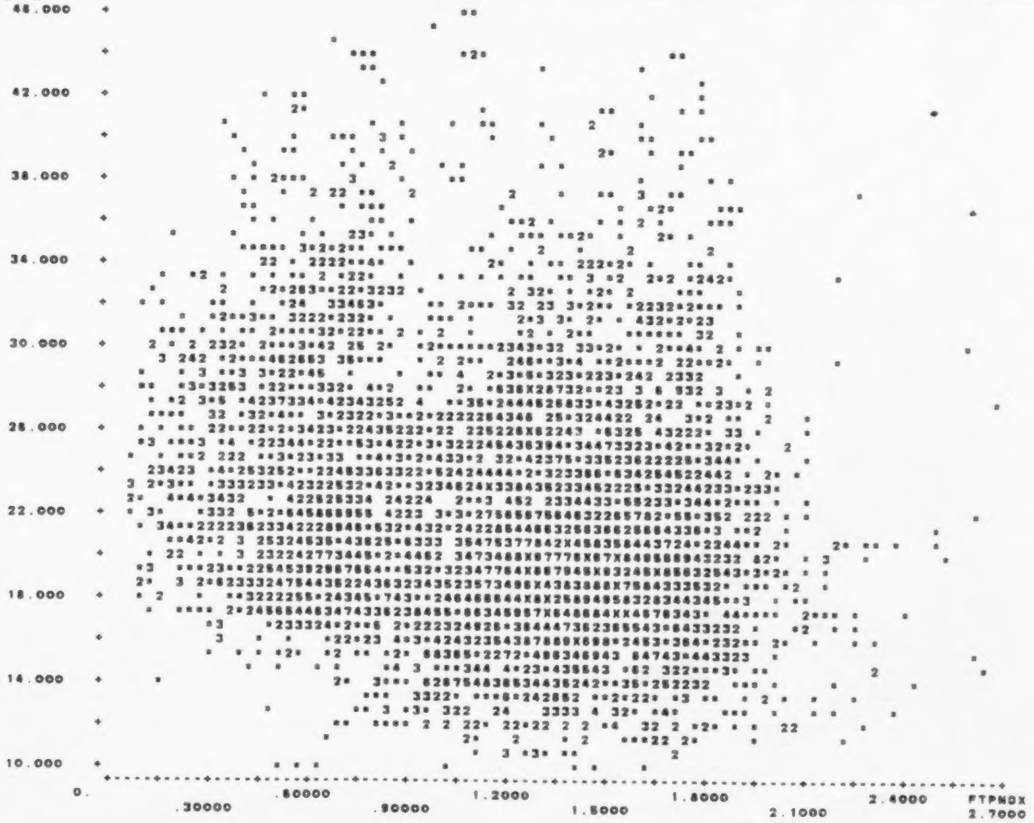


```
<SCATTER VAR=13;2 INTERVAL=(10,46);(0,18)>-SCATTER PLOT      N= 8057 OUT OF 10425  13.CMPG VS. 2.FTPCO
```

DATA BASE IS CERT/MFR



```
<SCATTER VAR=13;3 INTERVAL=(10,46);(0,2.7)>-SCATTER PLOT      N= 8083 OUT OF 10425  13.CMPG VS. 3.FTPNOX
```



Appendix 5

Results from Stepwise Backward Regression of Vehicle Parameters and Emissions versus Fuel Economy

```
<SELECT BYST OPTIONS=STEPWISE,BACKWARD VAR=11;22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V36:(1-7,10-17)>

SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)


ANALYSIS AT STEP 0 FOR 11.UMPG  N= 267 OUT OF 571

SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION          11    7883.6       716.69       216.66     0.
ERROR              255    843.52       3.3079
TOTAL              266    8727.1

MULTIPLE R= .95044  R-SQR= .90334  SE= 1.8188

     VARIABLE      PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

     CONSTANT                 4.2086       2.4755       1.7001     .0903
  22.VDHP         .19080      .26604       .85715 -1    3.1038     .0021
  23.DISP        -.05934     -.35044 -2    .36914 -2   -.94933     .3434
  24.RTHP        -.27595     -.32739 -1    .71410 -2   -4.5846     .0000
  27.NSVR        -.33923     -.11813       .20514 -1   -5.7585     .0000
  40.ETWM1        .73422      71940.       4165.7       17.270     .0000
   1.FTPHC        .07124      2.0918       1.8341       1.1405     .2552
   2.FTPCO       -.16276     -.31116       .11813      -2.6342     .0090
   3.FTPNOX       .15501      1.7071       .68127       2.5057     .0128
   4.FEHC        -.01475     -.90655       3.8490      -.23553     .8140
   5.FECO        -.03028     -.85001 -1    .17571      -.48375     .6290
   6.FENOX       -.09025     -.68149       .47095      -1.4471     .1491



ANALYSIS AT STEP 1 FOR 11.UMPG  N= 267 OUT OF 571

SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION          10    7883.4       788.34       239.20     0.
ERROR              256    843.71       3.2957
TOTAL              266    8727.1

MULTIPLE R= .95043  R-SQR= .90332  SE= 1.8154

     VARIABLE      PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

     CONSTANT                 4.2264       2.4698       1.7112     .0882
  22.VDHP         .19048      .26553       .85529 -1    3.1045     .0021
  23.DISP        -.05969     -.35241 -2    .36836 -2   -.95670     .3396
  24.RTHP        -.27800     -.32884 -1    .71015 -2   -4.6306     .0000
  27.NSVR        -.33895     -.11796       .20463 -1   -5.7644     .0000
  40.ETWM1        .73450      71883.       4150.8       17.318     .0000
   1.FTPHC        .07001      1.9644       1.7493       1.1229     .2625
   2.FTPCO       -.16234     -.30718       .11669      -2.6324     .0090
   3.FTPNOX       .15745      1.7245       .67600       2.5510     .0113
   5.FECO        -.05094     -.11109       .13614      -.81606     .4152
   6.FENOX       -.09135     -.68857       .46913      -1.4678     .1434

     REMAINING     PARTIAL   SIGNIF
```

```
    4.FEHC          -.01475     .8140



ANALYSIS AT STEP 2 FOR 11.UMPG  N= 267 OUT OF 571

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

REGRESSION               9    7881.2       875.69        266.05       0.
ERROR                  257    845.90       3.2915
TOTAL                  266    8727.1

MULTIPLE R= .95030  R-SQR= .90307  SE= 1.8142

     VARIABLE        PARTIAL   COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                   4.3017      2.4665        1.7440      .0823
  22.VDHP            .18581     .25731      .84879 -1    3.0315      .0027
  23.DISP           -.05848    -.34561 -2   .36803 -2   -.93909      .3486
  24.RTHP           -.28043    -.33192 -1   .70868 -2   -4.6836      .0000
  27.NSVR           -.34134    -.11887      .20419 -1   -5.8217      .0000
  40.ETWM1           .73406    71883.       4148.1        17.329      .0000
   1.FTPHC           .07525    2.1048       1.7397        1.2098      .2275
   2.FTPCO          -.18570    -.33634      .11101      -3.0297      .0027
   3.FTPNOX          .16065    1.7592       .67422        2.6093      .0096
   6.FENOX          -.08529    -.63765      .46466      -1.3723      .1712

    REMAINING        PARTIAL    SIGNIF

    4.FEHC          -.04355     .4862
    5.FECO          -.05094     .4152



ANALYSIS AT STEP 3 FOR 11.UMPG  N= 267 OUT OF 571

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

REGRESSION               8    7878.3       984.79        299.33       0.
ERROR                  258    848.81       3.2899
TOTAL                  266    8727.1

MULTIPLE R= .95013  R-SQR= .90274  SE= 1.8138

     VARIABLE        PARTIAL   COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                   3.3302      2.2385        1.4877      .1381
  22.VDHP            .17959     .24655      .84083 -1    2.9323      .0037
  24.RTHP           -.33737    -.36244 -1   .62962 -2   -5.7564      .0000
  27.NSVR           -.34910    -.11080      .18516 -1   -5.9839      .0000
  40.ETWM1           .76411    73322.       3853.8        19.026      .0000
   1.FTPHC           .07912    2.2126       1.7355        1.2749      .2035
   2.FTPCO          -.18366  -.33290      .11093     -3.0010       .0030
   3.FTPNOX          .15453   1.6802      .66880      2.5123       .0126
   6.FENOX          -.09243  -.68800      .46145     -1.4910       .1372

    REMAINING       PARTIAL   SIGNIF

  23.DISP           -.05848    .3486
   4.FEHC           -.04367    .4841
   5.FECO           -.04951    .4275



ANALYSIS AT STEP 4 FOR 11.UMPG  N= 267 OUT OF 571

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              7    7873.0       1124.7       341.04     O.
ERROR                 259    854.15       3.2979
TOTAL                 266    8727.1

MULTIPLE R= .94980  R-SQR= .90213  SE= 1.8160

    VARIABLE         PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

    CONSTANT                   3.6224      2.2295       1.6248     .1054
  22.VDHP             .17778    .24472     .84172 -1    2.9074     .0040
  24.RTHP            -.33019  -.35170 -1   .62471 -2   -5.6297     .0000
  27.NSVR            -.35656  -.11325      .18438 -1   -6.1419     .0000
  40.ETWM1            .76323   73350.      3858.4       19.011     .0000
   2.FTPCO           -.16714  -.26127      .95762 -1   -2.7283     .0068
   3.FTPNOX           .14868   1.6156      .66768       2.4197     .0162
   6.FENOX           -.07982  -.58646      .45507      -1.2887     .1986

    REMAINING        PARTIAL   SIGNIF

  23.DISP            -.06339    .3086
   1.FTPHC            .07912    .2035
   4.FEHC            -.02895    .6422
   5.FECO            -.05681    .3616



ANALYSIS AT STEP 5 FOR 11.UMPG  N= 267 OUT OF 571

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              6    7867.5       1311.3       396.60     O.
ERROR                 260    859.63       3.3063
TOTAL                 266    8727.1

MULTIPLE R= .94947  R-SQR= .90150  SE= 1.8183
```

```
      VARIABLE        PARTIAL  COEFFICIENT  STD ERROR    T-STAT      SIGNIF

      CONSTANT                   4.0430     2.2082       1.8309       .0683
   22.VDHP           .16886      .23093     .83595 -1   2.7625       .0061
   24.RTHP          -.33227    -.35501 -1   .62498 -2  -5.6804       .0000
   27.NSVR          -.35161    -.11151      .18412 -1  -6.0562       .0000
   40.ETWM1          .76303    72529.      3810.3       19.035       .0000
    2.FTPCO         -.15946    -.24837      .95358 -1  -2.6046       .0097
    3.FTPNOX         .13291      .98681     .45638       2.1623       .0315

      REMAINING       PARTIAL   SIGNIF

   23.DISP          -.07126     .2513
    1.FTPHC          .06391     .3037
    4.FEHC          -.02857     .6459
    5.FECO          -.04363     .4828
    6.FENOX         -.07982     .1986

 REGRESSION OF 11.UMPG USING BACKWARD SELECTION

 STEP    R-SQR   STD ERROR  # VAR      VARIABLE          PARTIAL  SIGNIF

   0    .90334    1.8188      11                    IN
   1    .90332    1.8154      10      4.FEHC        OUT  -.01475   .8140
   2    .90307    1.8142       9      5.FECO        OUT  -.05094   .4152
   3    .90274    1.8138       8     23.DISP        OUT  -.05848   .3486
   4    .90213    1.8160       7      1.FTPHC       OUT   .07912   .2035
   5    .90150    1.8183       6      6.FENOX       OUT  -.07982   .1986
```

```
<SELECT BYST OPTIONS=STEPWISE,BACKWARD VAR=11;22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V36:(1-7,10-17)*V28:(1,6,8)>

SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(CA,CA,CA)


ANALYSIS AT STEP 0 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              11     1675.5       152.32      76.138      .0000
ERROR                   85     170.04       2.0005
TOTAL                   96     1845.5

MULTIPLE R= .95282  R-SQR= .90786  SE= 1.4144

     VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

     CONSTANT                   9.9789       3.5123      2.8411      .0056
  22.VDHP           .12906      .14232       .11861      1.1999      .2335
  23.DISP          -.21762    -.94206 -2    .45829 -2   -2.0556      .0429
  24.RTHP          -.28686    -.23881 -1    .86502 -2   -2.7607      .0071
  27.NSVR          -.21535    -.57307 -1    .28186 -1   -2.0332      .0452
  40.ETWM1          .62636     51554.       6959.2       7.4080      .0000
   1.FTPHC         -.05356    -1.3776       2.7860      -.49446      .6223
   2.FTPCO          .04779     .64247 -1    .14565       .44111      .6603
   3.FTPNOX        -.05756    -.54008       1.0161      -.53152      .5964
   4.FEHC           .02906     .96623       3.6053       .26800      .7893
   5.FECO          -.13759    -.20991       .16390     -1.2807       .2038
   6.FENOX         -.06930    -.43213       .67474      -.64044      .5236



ANALYSIS AT STEP 1 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              10     1675.3       167.53      84.658      .0000
ERROR                   86     170.19       1.9789
TOTAL                   96     1845.5

MULTIPLE R= .95278  R-SQR= .90778  SE= 1.4067

     VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

     CONSTANT                   10.033       3.4875      2.8769      .0051
  22.VDHP           .12702      .13957       .11753      1.1875      .2383
  23.DISP          -.21673    -.93786 -2    .45555 -2   -2.0588      .0425
  24.RTHP          -.28613    -.23815 -1    .86000 -2   -2.7693      .0069
  27.NSVR          -.21714    -.57736 -1    .27988 -1   -2.0629      .0421
  40.ETWM1          .62643     51580.       6920.9       7.4527      .0000
   1.FTPHC         -.04783    -1.1918       2.6839      -.44408      .6581
   2.FTPCO          .04441     .59214 -1    .14365       .41221      .6812
   3.FTPNOX        -.06234    -.57931       1.0001      -.57926      .5639
   5.FECO          -.14360    -.18692       .13891     -1.3456       .1820
   6.FENOX         -.07067    -.44042       .67039      -.65696      .5130

     REMAINING      PARTIAL   SIGNIF
```

```
    4.FEHC              .02906    .7893


ANALYSIS AT STEP 2 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             9    1675.0        186.11      94.952      .0000
ERROR                 87    170.52        1.9600
TOTAL                 96    1845.5

MULTIPLE R= .95268  R-SQR= .90760  SE= 1.4000

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                  10.075      3.4693     2.9042      .0047
  22.VDHP           .12087    .13050       .11490     1.1358      .2592
  23.DISP          -.22191   -.95725 -2   .45095 -2  -2.1227      .0366
  24.RTHP          -.28715   -.23921 -1   .85550 -2  -2.7962      .0064
  27.NSVR          -.21693   -.57734 -1   .27855 -1  -2.0727      .0412
  40.ETWM1          .62696    51674.      6884.1      7.5063      .0000
   1.FTPHC         -.02547   -.49117      2.0670     -.23762      .8127
   3.FTPNOX        -.05164   -.45923      .95214     -.48231      .6308
   5.FECO          -.13749   -.17522      .13533    -1.2947       .1988
   6.FENOX         -.08255   -.50236      .65021     -.77262      .4418

     REMAINING      PARTIAL   SIGNIF

   2.FTPCO          .04441    .6812
   4.FEHC           .02306    .8311


ANALYSIS AT STEP 3 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             8    1674.9        209.36      107.97      .0000
ERROR                 88    170.63        1.9390
TOTAL                 96    1845.5

MULTIPLE R= .95265  R-SQR= .90754  SE= 1.3925

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                  10.019      3.4426     2.9103      .0046
  22.VDHP           .12290    .13243       .11399     1.1617      .2485
  23.DISP          -.22127   -.95431 -2   .44835 -2  -2.1285      .0361
  24.RTHP          -.30408   -.24484 -1   .81768 -2  -2.9943      .0036
  27.NSVR          -.21912   -.58214 -1   .27632 -1  -2.1067      .0380
  40.ETWM1          .62862    51789.      6830.1      7.5824      .0000
  3.FTPNOX          -.05174  -.46027       .94701      -.48603       .6282
  5.FECO            -.14141  -.17908       .13364      -1.3400       .1837
  6.FENOX           -.09570  -.55214       .61222      -.90187       .3696

    REMAINING        PARTIAL   SIGNIF

  1.FTPHC           -.02547     .8127
  2.FTPCO            .01822     .8654
  4.FEHC             .01694     .8748



ANALYSIS AT STEP 4 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              7    1674.4        239.20      124.43      .0000
ERROR                  89    171.09        1.9224
TOTAL                  96    1845.5

MULTIPLE R= .95252  R-SQR= .90729  SE= 1.3865

    VARIABLE        PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

    CONSTANT                  9.8343      3.4068      2.8867      .0049
 22.VDHP            .13294    .14163      .11193      1.2654      .2090
 23.DISP           -.22466   -.96883 -2   .44543 -2  -2.1750      .0323
 24.RTHP           -.30662   -.24704 -1   .81291 -2  -3.0390      .0031
 27.NSVR           -.21673   -.57556 -1   .27480 -1  -2.0944      .0391
 40.ETWM1           .62742    51650.      6794.8      7.6014      .0000
  5.FECO           -.14049   -.17811      .13305     -1.3387      .1841
  6.FENOX          -.15172   -.72290      .49922     -1.4481      .1511

    REMAINING       PARTIAL   SIGNIF

  1.FTPHC          -.02567     .8102
  2.FTPCO           .00570     .9575
  3.FTPNOX         -.05174     .6282
  4.FEHC            .02603     .8076



ANALYSIS AT STEP 5 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              6    1671.3        278.56      143.94      .0000
ERROR                  90    174.17        1.9352
TOTAL                  96    1845.5

MULTIPLE R= .95164  R-SQR= .90562  SE= 1.3911
```

```
     VARIABLE        PARTIAL   COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                    12.312      2.7970      4.4020      .0000
  23.DISP           -.20866   -.89726 -2    .44330 -2  -2.0240      .0459
  24.RTHP           -.34521   -.27437 -1    .78630 -2  -3.4894      .0008
  27.NSVR           -.17959   -.43938 -1    .25370 -1  -1.7319      .0867
  40.ETWM1           .65366    47003.       5736.3      8.1941      .0000
   5.FECO           -.14746   -.18846       .13324     -1.4144      .1607
   6.FENOX          -.17085   -.81514       .49552     -1.6450      .1035

     REMAINING       PARTIAL   SIGNIF

  22.VDHP            .13294    .2090
   1.FTPHC          -.03501    .7418
   2.FTPCO          -.02421    .8198
   3.FTPNOX         -.07265    .4937
   4.FEHC            .01960    .8537



ANALYSIS AT STEP 6 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            5    1667.5        333.50      170.45      .0000
ERROR                91    178.04        1.9565
TOTAL                96    1845.5

MULTIPLE R= .95054  R-SQR= .90353  SE= 1.3988

     VARIABLE        PARTIAL   COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                    12.124      2.8091      4.3160      .0000
  23.DISP           -.20477   -.88948 -2    .44570 -2  -1.9957      .0490
  24.RTHP           -.34552   -.27758 -1    .79029 -2  -3.5124      .0007
  27.NSVR           -.19037   -.47013 -1    .25415 -1  -1.8498      .0676
  40.ETWM1           .65307    47393.       5761.1      8.2265      .0000
   6.FENOX          -.13091   -.59618       .47329     -1.2596      .2110

     REMAINING       PARTIAL   SIGNIF

  22.VDHP            .14030    .1822
   1.FTPHC          -.05265    .6182
   2.FTPCO          -.05737    .5870
   3.FTPNOX         -.07120    .5000
   4.FEHC           -.05997    .5701
   5.FECO           -.14746    .1607



ANALYSIS AT STEP 7 FOR 11.UMPG  N= 97 OUT OF 198

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF
```

```
REGRESSION            4    1664.4        416.09        211.32        .0000
ERROR                92    181.15        1.9690
TOTAL                96    1845.5

MULTIPLE R= .94966  R-SQR= .90185  SE= 1.4032

     VARIABLE        PARTIAL   COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                    12.271     2.8156       4.3583      .0000
  23.DISP           -.26152   -.10874 -1    .41841 -2   -2.5989      .0109
  24.RTHP           -.32732   -.25856 -1    .77820 -2   -3.3225      .0013
  27.NSVR           -.17113   -.41940 -1    .25174 -1   -1.6660      .0991
  40.ETWM1           .64577    45957.       5665.0       8.1124      .0000

     REMAINING       PARTIAL    SIGNIF

  22.VDHP            .15534     .1371
   1.FTPHC          -.09808     .3496
   2.FTPCO          -.07625     .4676
   3.FTPNOX         -.13551     .1953
   4.FEHC           -.03018     .7740
   5.FECO           -.09798     .3501
   6.FENOX          -.13091     .2110

REGRESSION OF 11.UMPG USING BACKWARD SELECTION

STEP     R-SQR   STD ERROR  # VAR       VARIABLE            PARTIAL  SIGNIF

   0    .90786    1.4144      11                      IN
   1    .90778    1.4067      10     4.FEHC          OUT    .02906   .7893
   2    .90760    1.4000       9     2.FTPCO         OUT    .04441   .6812
   3    .90754    1.3925       8     1.FTPHC         OUT   -.02547   .8127
   4    .90729    1.3865       7     3.FTPNOX        OUT   -.05174   .6282
   5    .90562    1.3911       6    22.VDHP          OUT    .13294   .2090
   6    .90353    1.3988       5     5.FECO          OUT   -.14746   .1607
   7    .90185    1.4032       4     6.FENOX         OUT   -.13091   .2110
```

```
<SELECT RYST OPTIONS=STEPWISE BACKWARD VAR=1[illegible]-24,[illegible]10,1[illegible]MAXIM[illegible] STRA[illegible]50:8[illegible]6:(1[illegible]10-1[illegible]28:([illegible]4)>
 SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(CM,CM,CM)

 ANALYSIS AT STEP 0 FOR 11.UMPG  N= 107 OUT OF 233

 SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

 REGRESSION           11    3210.6        291.87      79.718     .0000
 ERROR                95    347.83        3.6613
 TOTAL               106    3558.4

 MULTIPLE R= .94987  R-SQR= .90225  SE= 1.9135

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

     CONSTANT                 7.1304      4.3368     1.6442       .1034
   22.VDHP          .16015    .25523      .16140     1.5814       .1171
   23.DISP          .10123    .83965 -2   .84662 -2   .99177      .3238
   24.RTHP         -.42421   -.73042 -1   .15997 -1 -4.5659       .0000
   27.NSVR         -.28486   -.11174      .38578 -1 -2.8965       .0047
   40.ETWM1         .74209    71856.      6659.0     10.791       .0000
    1.FTPHC         .21225    6.8089      3.2163     2.1170       .0369
    2.FTPCO        -.36298   -1.2555      .33067    -3.7969       .0003
    3.FTPNOX        .06603    .74025      1.1477      .64498      .5205
    4.FEHC         -.00005   -.50066 -2   10.631     -.47096 -3   .9996
    5.FECO         -.01161   -.95846 -1   .84708     -.11315      .9102
    6.FENOX         .04386    .32678      .76371      .42789      .6697


 ANALYSIS AT STEP 1 FOR 11.UMPG  N= 107 OUT OF 233

 SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

 REGRESSION           10    3210.6        321.06      88.613     .0000
 ERROR                96    347.83        3.6232
 TOTAL               106    3558.4

 MULTIPLE R= .94987  R-SQR= .90225  SE= 1.9035

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

     CONSTANT                 7.1308      4.2337     1.6843       .0954
   22.VDHP          .16206    .25522      .15861     1.6091       .1109
   23.DISP          .10226    .83959 -2   .83359 -2  1.0072       .3164
   24.RTHP         -.42729   -.73043 -1   .15774 -1 -4.6306       .0000
   27.NSVR         -.28894   -.11174      .37786 -1 -2.9571       .0039
   40.ETWM1         .75341    71855.      6400.6     11.226       .0000
    1.FTPHC         .24016    6.8081      2.8086     2.4240       .0172
    2.FTPCO        -.37663   -1.2555      .31516    -3.9835       .0001
    3.FTPNOX        .06605    .74026      1.1413      .64859      .5182
    5.FECO         -.01592   -.96118 -1   .61622     -.15598      .8764
    6.FENOX         .04420    .32674      .75367      .43353      .6656

     REMAINING      PARTIAL   SIGNIF
   4.FEHC           -.00005     .9996



ANALYSIS AT STEP 2 FOR 11.UMPG  N= 107 OUT OF 233

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             9    3210.5       356.73       99.456      .0000
ERROR                 97    347.91       3.5867
TOTAL                106    3558.4

MULTIPLE R= .94986  R-SQR= .90223  SE= 1.8939

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                 7.2003      4.1891      1.7188      .0888
  22.VDHP           .16143    .25180       .15629     1.6111      .1104
  23.DISP           .10440    .85295 -2    .82499 -2  1.0339      .3038
  24.RTHP          -.44424   -.73717 -1    .15095 -1 -4.8837      .0000
  27.NSVR          -.28881   -.11170       .37595 -1 -2.9710      .0037
  40.ETWM1          .75442    71760.      6339.4      11.320      .0000
   1.FTPHC          .24508    6.8752      2.7615      2.4897      .0145
   2.FTPCO         -.39308   -1.2690       .30141    -4.2103      .0001
   3.FTPNOX         .07126    .77943      1.1078       .70362     .4834
   6.FENOX          .04404    .32557       .74983      .43419     .6651

     REMAINING      PARTIAL    SIGNIF

   4.FEHC          -.01089     .9152
   5.FECO          -.01592     .8764



ANALYSIS AT STEP 3 FOR 11.UMPG  N= 107 OUT OF 233

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             8    3209.9       401.23       112.80      .0000
ERROR                 98    348.59       3.5571
TOTAL                106    3558.4

MULTIPLE R= .94976  R-SQR= .90204  SE= 1.8860

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                 6.7380      4.0347      1.6700      .0981
  22.VDHP           .17665    .26826       .15099     1.7766      .0787
  23.DISP           .10418    .85195 -2    .82157 -2  1.0370      .3023
  24.RTHP          -.44271   -.72905 -1    .14916 -1 -4.8876      .0000
  27.NSVR          -.29018   -.11231       .37413 -1 -3.0018      .0034
  40.ETWM1          .76663    72423.      6127.4      11.819      .0000
  1.FTPHC           .24343   6.8272     2.7478     2.4846      .0147
  2.FTPCO         -.39462  -1.2749      .29986    -4.2516      .0000
  3.FTPNOX          .17271   1.1618     .66930     1.7358      .0857

    REMAINING      PARTIAL    SIGNIF

  4.FEHC          -.00646     .9494
  5.FECO          -.01546     .8793
  6.FENOX          .04404     .6651


ANALYSIS AT STEP 4 FOR 11.UMPG  N= 107 OUT OF 233

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            7    3206.0       458.00       128.66      .0000
ERROR                99    352.42       3.5598
TOTAL               106    3558.4

MULTIPLE R= .94919  R-SQR= .90096  SE= 1.8867

    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

    CONSTANT                   8.2543     3.7618     2.1942      .0306
 22.VDHP            .16297     .24566     .14947     1.6435      .1034
 24.RTHP          -.46100  -.64389 -1   .12457 -1  -5.1690      .0000
 27.NSVR          -.31861  -.12156      .36347 -1  -3.3444      .0012
 40.ETWM1           .77008   70630.      5880.6     12.011       .0000
  1.FTPHC           .23559   6.6113     2.7410     2.4120      .0177
  2.FTPCO         -.39087  -1.2670      .29988    -4.2252      .0001
  3.FTPNOX          .21354   1.3814     .63516     2.1748      .0320

    REMAINING      PARTIAL    SIGNIF

 23.DISP            .10418    .3023
  4.FEHC          -.00277     .9781
  5.FECO          -.02601     .7973
  6.FENOX           .04351    .6673


ANALYSIS AT STEP 5 FOR 11.UMPG  N= 107 OUT OF 233

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            6    3196.4       532.74       147.15      .0000
ERROR               100    362.03       3.6203
TOTAL               106    3558.4

MULTIPLE R= .94777  R-SQR= .89826  SE= 1.9027
```

```
    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

    CONSTANT                  11.346      3.2852      3.4537      .0008
 24.RTHP          -.47041   -.66582 -1   .12490 -1  -5.3308      .0000
 27.NSVR          -.28375   -.10324      .34888 -1  -2.9591      .0039
 40.ETWM1          .77699    66628.      5398.2      12.343      .0000
  1.FTPHC          .23016    6.5367      2.7638      2.3651      .0200
  2.FTPCO         -.39295   -1.2908      .30206     -4.2733      .0000
  3.FTPNOX         .20405    1.3337      .63988      2.0844      .0397

    REMAINING      PARTIAL   SIGNIF

 22.VDHP           .16297    .1034
 23.DISP           .07818    .4371
  4.FEHC           .03518    .7269
  5.FECO           .00074    .9942
  6.FENOX          .08161    .4172

REGRESSION OF 11.UMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR      VARIABLE          PARTIAL   SIGNIF

  0    .90225   1.9135      11                    IN
  1    .90225   1.9035      10      4.FEHC        OUT  -.00005    .9996
  2    .90223   1.8939       9      5.FECO        OUT  -.01592    .8764
  3    .90204   1.8860       8      6.FENOX       OUT   .04404    .6651
  4    .90096   1.8867       7     23.DISP        OUT   .10418    .3023
  5    .89826   1.9027       6     22.VDHP        OUT   .16297    .1034
```

```
<SELECT RYST OPTIONS=STEPWISE BACKWARD VAR=11:22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V26:(1-7,10-17)*V28:(7,9)>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(LA,LA)


ANALYSIS AT STEP 0 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             11     312.30       28.391      55.376      .0000
ERROR                  51     26.148       .51270
TOTAL                  62     338.45

MULTIPLE R= .96059  R-SQR= .92274  SE= .71603

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                  20.401      2.4956     8.1747      .0000
  22.VDHP          -.18428   -.12310       .91935 -1  -1.3390      .1865
  23.DISP          -.61733   -.25572 -1    .45633 -2  -5.6039      .0000
  24.RTHP          -.15213   -.74497 -2    .67774 -2  -1.0992      .2768
  27.NSVR          -.19583   -.42972 -1    .30132 -1  -1.4261      .1599
  40.ETWM1          .52819    27964.       6295.0      4.4423      .0000
   1.FTPHC         -.25446   -4.2266       2.2493     -1.8791      .0660
   2.FTPCO          .10770    .91243 -1    .11794      .77363     .4427
   3.FTPNOX         .45293    2.3989       .66122      3.6281     .0007
   4.FEHC           .08627    3.9081       6.3194      .61843     .5390
   5.FECO          -.11779   -.18839       .22239     -.84711     .4009
   6.FENOX         -.34244   -1.2723       .48881     -2.6029     .0121



ANALYSIS AT STEP 1 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             10     312.11       31.211      61.607      .0000
ERROR                  52     26.344       .50662
TOTAL                  62     338.45

MULTIPLE R= .96029  R-SQR= .92216  SE= .71177

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                  20.047      2.4149     8.3015      .0000
  22.VDHP          -.17041   -.11162       .89506 -1  -1.2471      .2180
  23.DISP          -.61391   -.25380 -1    .45256 -2  -5.6081      .0000
  24.RTHP          -.15655   -.76878 -2    .67262 -2  -1.1430      .2583
  27.NSVR          -.18382   -.39802 -1    .29516 -1  -1.3485      .1833
  40.ETWM1          .53469    28385.       6220.9      4.5627      .0000
   1.FTPHC         -.25480   -3.3868       1.7825     -1.9001      .0630
   2.FTPCO          .07840    .60137 -1    .10604      .56710     .5731
   3.FTPNOX         .45351    2.4108       .65700      3.6693     .0006
   5.FECO          -.08973   -.66472 -1    .10231     -.64969     .5187
   6.FENOX         -.33628   -1.2466       .48414     -2.5749     .0129

     REMAINING      PARTIAL   SIGNIF
```

```
4.FEHC            .08627    .5390


ANALYSIS AT STEP 2 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE                  DF    SUM OF SQRS  MEAN SQUARE    F-STAT     SIGNIF

REGRESSION               9     311.95       34.661       69.303      .0000
ERROR                   53     26.507       .50013
TOTAL                   62     338.45

MULTIPLE R= .96004  R-SQR= .92168  SE= .70720

    VARIABLE      PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

    CONSTANT                  20.072      2.3990      8.3665      .0000
 22.VDHP          -.15451   -.96890 -1    .85104 -1  -1.1385      .2600
 23.DISP          -.61533   -.25517 -1    .44902 -2  -5.6829      .0000
 24.RTHP          -.16833   -.82255 -2    .66163 -2  -1.2432      .2193
 27.NSVR          -.17040   -.35907 -1    .28521 -1  -1.2590      .2136
 40.ETWM1          .53064    27868.       6114.4      4.5578      .0000
   1.FTPHC        -.24869   -2.8986       1.5507     -1.8692      .0671
   3.FTPNOX        .44861    2.3734       .64950      3.6542      .0006
   5.FECO         -.06350   -.43104 -1    .93046 -1  -.46325      .6451
   6.FENOX        -.34716   -1.2842       .47650     -2.6950      .0094

    REMAINING     PARTIAL    SIGNIF

   2.FTPCO        .07840     .5731
   4.FEHC         .04436     .7501


ANALYSIS AT STEP 3 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE                  DF    SUM OF SQRS  MEAN SQUARE    F-STAT     SIGNIF

REGRESSION               8     311.84       38.980       79.089      .0000
ERROR                   54     26.614       .49286
TOTAL                   62     338.45

MULTIPLE R= .95988  R-SQR= .92136  SE= .70204

    VARIABLE      PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

    CONSTANT                  20.151      2.3755      8.4828      .0000
 22.VDHP          -.17057   -.10511       .82628 -1  -1.2720      .2088
 23.DISP          -.61580   -.25586 -1    .44549 -2  -5.7433      .0000
 24.RTHP          -.16492   -.80582 -2    .65582 -2  -1.2287      .2245
 27.NSVR          -.16917   -.35708 -1    .28310 -1  -1.2613      .2126
 40.ETWM1          .52917    27811.       6068.5      4.5828      .0000
```

```
  1.FTPHC          -.25953  -3.0059      1.5221     -1.9749       .0534
  3.FTPNOX          .44742   2.3702       .64472     3.6764       .0005
  6.FENOX          -.34227  -1.2370       .46212    -2.6769       .0098

    REMAINING      PARTIAL   SIGNIF

  2.FTPCO           .04604    .7386
  4.FEHC           -.03238    .8144
  5.FECO           -.06350    .6451


ANALYSIS AT STEP 4 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE               DF   SUM OF SQRS  MEAN SQUARE    F-STAT     SIGNIF

REGRESSION            7    311.09        44.442       89.344      .0000
ERROR                55    27.358        .49743
TOTAL                62    338.45

MULTIPLE R= .95873  R-SQR= .91917  SE= .70528

    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

    CONSTANT                  19.979      2.3824      8.3864      .0000
 22.VDHP           -.13387  -.80730 -1   .80582 -1  -1.0018      .3208
 23.DISP           -.78279  -.29464 -1   .31583 -2  -9.3291      .0000
 27.NSVR           -.21140  -.44230 -1   .27574 -1  -1.6041      .1144
 40.ETWM1           .53510   28512.      6069.6      4.6975      .0000
  1.FTPHC          -.27289  -3.1995      1.5209     -2.1036      .0400
  3.FTPNOX          .45115   2.4229       .64627     3.7490      .0004
  6.FENOX          -.33582  -1.2274       .46419    -2.6441      .0107

    REMAINING      PARTIAL   SIGNIF

 24.RTHP           -.16492    .2245
  2.FTPCO           .06975    .6095
  4.FEHC           -.02487    .8556
  5.FECO           -.05354    .6951


ANALYSIS AT STEP 5 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE               DF   SUM OF SQRS  MEAN SQUARE    F-STAT     SIGNIF

REGRESSION            6    310.60        51.766       104.06      .0000
ERROR                56    27.858        .49746
TOTAL                62    338.45

MULTIPLE R= .95796  R-SQR= .91769  SE= .70531
```

```
     VARIABLE        PARTIAL   COEFFICIENT   STD ERROR    T-STAT      SIGNIF

     CONSTANT                     18.660       1.9853      9.3992      .0000
  23.DISP            -.77842   -.29027 -1    .31281 -2   -9.2794      .0000
  27.NSVR            -.17474   -.34039 -1    .25629 -1   -1.3281      .1895
  40.ETWM1            .53217    28551.       6069.7       4.7038      .0000
   1.FTPHC           -.28179   -3.3304       1.5154      -2.1977      .0321
   3.FTPNOX           .45288    2.4539       .64555       3.8012      .0004
   6.FENOX           -.34509   -1.2715       .46211      -2.7515      .0080

     REMAINING       PARTIAL    SIGNIF

  22.VDHP            -.13387     .3208
  24.RTHP            -.12651     .3484
   2.FTPCO            .01270     .9253
   4.FEHC            -.05457     .6868
   5.FECO            -.08202     .5442


ANALYSIS AT STEP 6 FOR 11.UMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT      SIGNIF

REGRESSION             5     309.72        61.944      122.87      .0000
ERROR                 57     28.735        .50412
TOTAL                 62     338.45

MULTIPLE R= .95661  R-SQR= .91510  SE= .71002

     VARIABLE        PARTIAL   COEFFICIENT   STD ERROR    T-STAT      SIGNIF

     CONSTANT                     18.563       1.9972      9.2945      .0000
  23.DISP            -.77173   -.28812 -1    .31448 -2   -9.1618      .0000
  40.ETWM1            .55091    23388.       4692.9       4.9838      .0000
   1.FTPHC           -.24360   -2.7841       1.4682      -1.8963      .0630
   3.FTPNOX           .47170    2.5909       .64151       4.0388      .0002
   6.FENOX           -.32324   -1.1887       .46095      -2.5789      .0125

     REMAINING       PARTIAL    SIGNIF

  22.VDHP            -.05804     .6652
  24.RTHP            -.17631     .1855
  27.NSVR            -.17474     .1895
   2.FTPCO            .00791     .9530
   4.FEHC            -.03891     .7718
   5.FECO            -.05924     .6587

REGRESSION OF 11.UMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR       VARIABLE          PARTIAL   SIGNIF

   0   .92274    .71603      11                     IN
   1   .92216    .71177      10     4.FEHC          OUT   .08627    .5390
  2   .92168   .70720       9    2.FTPCO       OUT   .07840   .5731
  3   .92136   .70204       8    5.FECO        OUT  -.06350   .6451
  4   .91917   .70528       7   24.RTHP        OUT  -.16492   .2245
  5   .91769   .70531       6   22.VDHP        OUT  -.13387   .3208
  6   .91510   .71002       5   27.NSVR        OUT  -.17474   .1895
```

```
<SELECT BYST OPTIONS=STEPWISE,BACKWARD VAR=12;22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V36:(1-7,10-17)>

SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)


ANALYSIS AT STEP 0 FOR 12.HMPG  N= 267 OUT OF 571

SOURCE               DF    SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           11     13779.        1252.7      151.14     0.
ERROR               255     2113.5        8.2883
TOTAL               266     15893.

MULTIPLE R= .93114  R-SQR= .86701  SE= 2.8789


     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

     CONSTANT                  32.215      3.9185      8.2213      .0000
  22.VDHP          -.19500   -.43076       .13568     -3.1748      .0017
  23.DISP          -.28485   -.27727 -1    .58431 -2  -4.7452      .0000
  24.RTHP          -.16999   -.31137 -1    .11304 -1  -2.7547      .0063
  27.NSVR          -.62413   -.41422       .32472 -1  -12.756      .0000
  40.ETWM1          .61618    82379.      6593.9       12.493      .0000
   1.FTPHC          .16478    7.7455      2.9032       2.6679      .0081
   2.FTPCO         -.17405   -.52776       .18698     -2.8225      .0051
   3.FTPNOX         .10556    1.8279      1.0784       1.6951      .0913
   4.FEHC          -.02990   -2.9099      6.0926      -.47761      .6333
   5.FECO           .00697    .30963 -1    .27814      .11132      .9114
   6.FENOX         -.04408   -.52522       .74547     -.70455      .4817




ANALYSIS AT STEP 1 FOR 12.HMPG  N= 267 OUT OF 571

SOURCE               DF    SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           10     13779.        1377.9      166.89     0.
ERROR               256     2113.6        8.2563
TOTAL               266     15893.

MULTIPLE R= .93113  R-SQR= .86701  SE= 2.8734


     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

     CONSTANT                  32.211      3.9108      8.2365      .0000
  22.VDHP          -.19503   -.42962       .13503     -3.1816      .0016
  23.DISP          -.28517   -.27748 -1    .58289 -2  -4.7604      .0000
  24.RTHP          -.17009   -.31154 -1    .11281 -1  -2.7617      .0062
  27.NSVR          -.62472   -.41398       .32340 -1  -12.801      .0000
  40.ETWM1          .61631    82352.      6576.6       12.522      .0000
   1.FTPHC          .16864    7.6618      2.7989       2.7375      .0066
   2.FTPCO         -.18147   -.52098       .17645     -2.9525      .0034
   3.FTPNOX         .10571    1.8303      1.0761       1.7009      .0902
   4.FEHC          -.03285   -2.4822      4.7199      -.52591      .5994
   6.FENOX         -.04554   -.53711       .73636     -.72941      .4664

     REMAINING      PARTIAL   SIGNIF
   5.FECO            .00697    .9114



ANALYSIS AT STEP 2 FOR 12.HMPG  N= 267 OUT OF 571

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT      SIGNIF

REGRESSION             9    13777.        1530.8      185.93      0.
ERROR                257    2115.9        8.2331
TOTAL                266    15893.

MULTIPLE R= .93106  R-SQR= .86686  SE= 2.8693

    VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

    CONSTANT                   32.308      3.9009      8.2823      .0000
  22.VDHP          -.19870  -.43631        .13424     -3.2501      .0013
  23.DISP          -.28513  -.27758 -1     .58206 -2  -4.7689      .0000
  24.RTHP          -.17399  -.31748 -1     .11208 -1  -2.8326      .0050
  27.NSVR          -.62462  -.41409        .32294 -1  -12.823      .0000
  40.ETWM1          .61577   82194.       6560.5       12.529      .0000
   1.FTPHC          .16552   7.4033       2.7515       2.6906      .0076
   2.FTPCO         -.18465  -.52882        .17558     -3.0119      .0029
   3.FTPNOX         .11049   1.9004       1.0663       1.7822      .0759
   6.FENOX         -.04441  -.52373        .73488     -.71267      .4767

    REMAINING       PARTIAL   SIGNIF

   4.FEHC          -.03285    .5994
   5.FECO          -.01531    .8067



ANALYSIS AT STEP 3 FOR 12.HMPG  N= 267 OUT OF 571

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT      SIGNIF

REGRESSION             8    13773.        1721.6      209.51      0.
ERROR                258    2120.1        8.2174
TOTAL                266    15893.

MULTIPLE R= .93091  R-SQR= .86660  SE= 2.8666

    VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

    CONSTANT                   32.847      3.8234      8.5910      .0000
  22.VDHP          -.20432  -.44688        .13329     -3.3527      .0009
  23.DISP          -.29115  -.28237 -1     .57762 -2  -4.8884      .0000
  24.RTHP          -.17234  -.31446 -1     .11190 -1  -2.8103      .0053
  27.NSVR          -.62425  -.41409        .32263 -1  -12.835      .0000
  40.ETWM1          .61836   81297.       6432.6       12.638      .0000
```

```
   1.FTPHC          .16025   7.0529      2.7046      2.6077       .0096
   2.FTPCO        -.17981  -.50741      .17282     -2.9360       .0036
   3.FTPNOX         .11182   1.3640      .75464      1.8075       .0719

     REMAINING      PARTIAL   SIGNIF

   4.FEHC         -.03127     .6165
   5.FECO         -.00925     .8823
   6.FENOX        -.04441     .4767

REGRESSION OF 12.HMPG USING BACKWARD SELECTION

STEP     R-SQR  STD ERROR  # VAR       VARIABLE          PARTIAL  SIGNIF

   0   .86701    2.8789      11                     IN
   1   .86701    2.8734      10      5.FECO        OUT    .00697    .9114
   2   .86686    2.8693       9      4.FEHC        OUT  -.03285    .5994
   3   .86660    2.8666       8      6.FENOX       OUT  -.04441    .4767
```

```
<SELECT RYST OPTIONS=STEPWISE,BACKWARD VAR=12:22-24,27,40,1-6 MAXIM [illegible] STRAT=V50:81*V26:(1-7,10-17)*V28:(1-6,8)>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(CA,CA,CA)

ANALYSIS AT STEP 0 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

REGRESSION            11    2323.3       211.21       40.517     .0000
ERROR                 85    443.10       5.2129
TOTAL                 96    2766.4

MULTIPLE R= .91642  R-SQR= .83983  SE= 2.2832

   VARIABLE      PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

   CONSTANT                  38.402      5.6697       6.7733     .0000
 22.VDHP         -.39941   -.76909       .19147      -4.0167     .0001
 23.DISP         -.19307   -.13421  -1   .73980  -2  -1.8141     .0732
 24.RTHP         -.35372   -.48685  -1   .13964  -1  -3.4866     .0008
 27.NSVR         -.36055   -.16215       .45499  -1  -3.5639     .0006
 40.ETWM1         .32891    36073.       11234.       3.2111     .0019
  1.FTPHC        -.04053   -1.6818       4.4974      -.37395     .7094
  2.FTPCO         .11524     .25148      .23511       1.0696     .2878
  3.FTPNOX       -.08355   -1.2678       1.6403      -.77295     .4417
  4.FEHC          .02485    1.3336       5.8198       .22915     .8193
  5.FECO         -.02737   -.66781  -1   .26457      -.25241     .8013
  6.FENOX         .01979     .19878      1.0892       .18250     .8556


ANALYSIS AT STEP 1 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

REGRESSION            10    2323.2       232.32       45.072     .0000
ERROR                 86    443.27       5.1543
TOTAL                 96    2766.4

MULTIPLE R= .91639  R-SQR= .83977  SE= 2.2703

   VARIABLE      PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

   CONSTANT                  38.379      5.6363       6.8093     .0000
 22.VDHP         -.40035   -.77064       .19021      -4.0516     .0001
 23.DISP         -.19323   -.13139  -1   .71940  -2  -1.8264     .0713
 24.RTHP         -.36969   -.49366  -1   .13379  -1  -3.6897     .0004
 27.NSVR         -.36141   -.16249       .45205  -1  -3.5945     .0005
 40.ETWM1         .33027    36189.       11153.       3.2449     .0017
  1.FTPHC        -.03567   -1.3667       4.1294      -.33098     .7415
  2.FTPCO         .11375     .24170      .22763       1.0618     .2913
  3.FTPNOX       -.08733   -1.1010       1.3543      -.81299     .4185
  4.FEHC          .02396    1.2849       5.7809       .22227     .8246
  5.FECO         -.03093   -.74519  -1   .25968      -.28697     .7748

   REMAINING     PARTIAL   SIGNIF
   6.FENOX          .01979    .8556



ANALYSIS AT STEP 2 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE . F-STAT     SIGNIF

REGRESSION              9   2322.9        258.10       50.627      .0000
ERROR                  87   443.53        5.0980
TOTAL                  96   2766.4

MULTIPLE R= .91634  R-SQR= .83967  SE= 2.2579

    VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

    CONSTANT                   38.453     5.5958      6.8717      .0000
  22.VDHP          -.40303   -.77422       .18848    -4.1076      .0001
  23.DISP          -.19267   -.13099 -1    .71523 -2 -1.8314      .0705
  24.RTHP          -.36907   -.49241 -1    .13294 -1 -3.7039      .0004
  27.NSVR          -.36286   -.16304       .44890 -1 -3.6321      .0005
  40.ETWM1          .33043    36217.      11091.      3.2655      .0016
   1.FTPHC         -.03064   -1.1367      3.9757     -.28591      .7756
   2.FTPCO          .11168     .23554      .22470     1.0482      .2974
   3.FTPNOX        -.09412   -1.1626      1.3185     -.88178      .3803
   5.FECO          -.02140   -.43461 -1    .21768    -.19966      .8422

    REMAINING       PARTIAL   SIGNIF

   4.FEHC           .02396    .8246
   6.FENOX          .01867    .8630



ANALYSIS AT STEP 3 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              8   2322.7        290.34       57.579      .0000
ERROR                  88   443.73        5.0424
TOTAL                  96   2766.4

MULTIPLE R= .91630  R-SQR= .83960  SE= 2.2455

    VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

    CONSTANT                   38.379     5.5530      6.9113      .0000
  22.VDHP          -.40288   -.77403       .18745    -4.1292      .0001
  23.DISP          -.19217   -.13063 -1    .71109 -2 -1.8370      .0696
  24.RTHP          -.37012   -.49363 -1    .13208 -1 -3.7375      .0003
  27.NSVR          -.36616   -.16395       .44416 -1 -3.6912      .0004
  40.ETWM1          .33290    36402.      10992.      3.3118      .0013
```

```
   1.FTPHC            -.02800  -1.0293      3.9176      -.26273       .7934
   2.FTPCO             .10998   .22361      .21543      1.0380        .3021
   3.FTPNOX           -.09169  -1.0978      1.2709      -.86379       .3901

     REMAINING        PARTIAL   SIGNIF

   4.FEHC              .00868    .9357
   5.FECO             -.02140    .8422
   6.FENOX             .02285    .8317



ANALYSIS AT STEP 4 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                  DF    SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION               7     2322.4        331.76      66.490       .0000
ERROR                   89     444.08        4.9897
TOTAL                   96     2766.4

MULTIPLE R= .91623  R-SQR= .83948  SE= 2.2338

     VARIABLE         PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

     CONSTANT                    38.353      5.5230      6.9442       .0000
  22.VDHP             -.40442  -.77672       .18619     -4.1716       .0001
  23.DISP             -.19780  -.13329 -1    .70015 -2  -1.9037       .0602
  24.RTHP             -.37637  -.49852 -1    .13008 -1  -3.8325       .0002
  27.NSVR             -.36690  -.16432       .44161 -1  -3.7208       .0003
  40.ETWM1             .33423   36539.      10922.       3.3456       .0012
   2.FTPCO             .11640   .18971       .17159      1.1056       .2719
   3.FTPNOX           -.09444  -1.1271      1.2594      -.89491       .3732

     REMAINING        PARTIAL   SIGNIF

   1.FTPHC            -.02800    .7934
   4.FEHC              .00452    .9663
   5.FECO             -.01741    .8707
   6.FENOX             .00962    .9283



ANALYSIS AT STEP 5 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                  DF    SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION               6     2318.4        386.39      77.610       .0000
ERROR                   90     448.08        4.9786
TOTAL                   96     2766.4

MULTIPLE R= .91544  R-SQR= .83803  SE= 2.2313
```

```
     VARIABLE        PARTIAL   COEFFICIENT   STD ERROR      T-STAT      SIGNIF

     CONSTANT                    37.916      5.4953        6.8997       .0000
  22.VDHP          -.39573    -.75162        .18386       -4.0879       .0001
  23.DISP          -.23287    -.15179  -1    .36818  -2   -2.2717       .0255
  24.RHTP          -.36796    -.48396  -1    .12891  -1   -3.7542       .0003
  27.NSVR          -.35894    -.15995        .43842  -1   -3.6483       .0004
  40.ETWM1          .32658     35593.        10858.        3.2780       .0015
   2.FTPCO          .09553     .15101        .16587        .91042       .3650

    REMAINING        PARTIAL    SIGNIF

   1.FTPHC         -.03603     .7345
   3.FTPNOX        -.09444     .3732
   4.FEHC           .03171     .7654
   5.FECO           .00739     .9446
   6.FENOX         -.04787     .6523


ANALYSIS AT STEP 6 FOR 12.HMPG  N= 97 OUT OF 198

SOURCE                DF   SUM OF SQRS   MEAN SQUARE    F-STAT      SIGNIF

REGRESSION             5     2314.2        462.85       93.142       .0000
ERROR                 91     452.20        4.9693
TOTAL                 96     2766.4

MULTIPLE R= .91463  R-SQR= .83654  SE= 2.2292

     VARIABLE        PARTIAL   COEFFICIENT   STD ERROR      T-STAT      SIGNIF

     CONSTANT                    38.462      5.4573        7.0478       .0000
  22.VDHP          -.42312    -.79295        .17800       -4.4547       .0000
  23.DISP          -.23508    -.15392  -1    .66714  -2   -2.3072       .0233
  24.RTHP          -.35878    -.46765  -1    .12754  -1   -3.6667       .0004
  27.NSVR          -.35437    -.15819        .43758  -1   -3.6151       .0005
  40.ETWM1          .32421     35464.        10847.        3.2694       .0015

    REMAINING        PARTIAL    SIGNIF

   1.FTPHC          .03125     .7674
   2.FTPCO          .09553     .3650
   3.FTPNOX        -.06690     .5263
   4.FEHC           .03926     .7102
   5.FECO           .02353     .8238
   6.FENOX         -.03533     .7381

REGRESSION OF 12.HMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR       VARIABLE           PARTIAL   SIGNIF

  0    .83983   2.2832       11                       IN
  1    .83977   2.2703       10      6.FENOX          OUT   .01979    .8556
```

```
 2   .83967   2.2579        9    4.FEHC        OUT    .02396   .8246
 3   .83960   2.2455        8    5.FECO        OUT  -.02140   .8422
 4   .83948   2.2338        7    1.FTPHC       OUT  -.02800   .7934
 5   .83803   2.2313        6    3.FTPNOX      OUT  -.09444   .3732
 6   .83654   2.2292        5    2.FTPCO       OUT    .09553   .3650
```

```
<SELECT BYST OPTIONS=STEPWISE,BACKWARD VAR=12;22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V36:(1-7,10-17)*V28:(2,3,4)>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(CM,CM,CM)

ANALYSIS AT STEP 0 FOR 12.HMPG  N= 107 OUT OF 233

SOURCE                 DF    SUM OF SQRS   MEAN SQUARE    F-STAT      SIGNIF

REGRESSION             11     4351.9        395.63        71.276       .0000
ERROR                  95     527.31        5.5506
TOTAL                 106     4879.2

MULTIPLE R= .94442  R-SQR= .89193  SE= 2.3560

     VARIABLE         PARTIAL   COEFFICIENT   STD ERROR    T-STAT      SIGNIF

     CONSTANT                      45.357      5.3397       8.4942      .0000
  22.VDHP            -.41494    -.88332        .19872      -4.4450      .0000
  23.DISP            -.29967    -.31913 -1     .10424 -1   -3.0615      .0029
  24.RTHP            -.29259    -.58742 -1     .19697 -1   -2.9823      .0036
  27.NSVR            -.58100    -.33049        .47500 -1   -6.9577      .0000
  40.ETWM1            .61891    62969.        8199.0        7.6801      .0000
   1.FTPHC            .15397    6.0146        3.9601        1.5188      .1321
   2.FTPCO           -.31942    -1.3376        .40714      -3.2854      .0014
   3.FTPNOX           .13156    1.8279        1.4131        1.2935      .1990
   4.FEHC             .11390    14.626        13.089        1.1174      .2666
   5.FECO            -.04838    -.49236       1.0430       -.47207      .6380
   6.FENOX           -.01944    -.17824        .94033      -.18955      .8501


ANALYSIS AT STEP 1 FOR 12.HMPG  N= 107 OUT OF 233

SOURCE                 DF    SUM OF SQRS   MEAN SQUARE    F-STAT      SIGNIF

REGRESSION             10     4351.7        435.17        79.195       .0000
ERROR                  96     527.51        5.4949
TOTAL                 106     4879.2

MULTIPLE R= .94440  R-SQR= .89189  SE= 2.3441

     VARIABLE         PARTIAL   COEFFICIENT   STD ERROR    T-STAT      SIGNIF

     CONSTANT                      45.580      5.1817       8.7965      .0000
  22.VDHP            -.42618    -.89140        .19312      -4.6159      .0000
  23.DISP            -.29934    -.31874 -1     .10370 -1   -3.0738      .0028
  24.RTHP            -.29549    -.59107 -1     .19504 -1   -3.0306      .0031
  27.NSVR            -.58082    -.33036        .47256 -1   -6.9909      .0000
  40.ETWM1            .62449    62664.        7998.9        7.8341      .0000
   1.FTPHC            .15636    6.0848        3.9229        1.5511      .1242
   2.FTPCO           -.31925    -1.3371        .40508      -3.3007      .0014
   3.FTPNOX           .18277    1.6205         .88966       1.8214      .0717
   4.FEHC             .11236    14.313        12.919        1.1079      .2707
   5.FECO            -.04699    -.47679       1.0345       -.46089      .6459

     REMAINING        PARTIAL     SIGNIF
  6.FENOX          -.01944    .8501



ANALYSIS AT STEP 2 FOR 12.HMPG  N= 107 OUT OF 233

SOURCE              DF   SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

REGRESSION           9     4350.5        483.39       88.691       .0000
ERROR               97     528.67        5.4503
TOTAL              106     4879.2

MULTIPLE R= .94427  R-SQR= .89165  SE= 2.3346

    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT      SIGNIF

    CONSTANT                  45.401      5.1460      8.8225       .0000
  22.VDHP         -.42507   -.88930       .19228     -4.6251       .0000
  23.DISP         -.29601   -.31059 -1    .10176 -1  -3.0522       .0029
  24.RTHP         -.30076   -.60019 -1    .19324 -1  -3.1059       .0025
  27.NSVR         -.58590   -.33288       .46748 -1  -7.1207       .0000
  40.ETWM1         .62998    63132.       7902.1      7.9893       .0000
   1.FTPHC         .19245    6.8456       3.5442      1.9315       .0563
   2.FTPCO        -.35965   -1.4099       .37142     -3.7961       .0003
   3.FTPNOX        .20775    1.7534       .83822      2.0918       .0391
   4.FEHC          .10978    10.267       9.4380      1.0878       .2794

    REMAINING      PARTIAL    SIGNIF

   5.FECO         -.04699      .6459
   6.FENOX        -.01566      .8783



ANALYSIS AT STEP 3 FOR 12.HMPG  N= 107 OUT OF 233

SOURCE              DF   SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

REGRESSION           8     4344.1        543.01       99.444       .0000
ERROR               98     535.12        5.4604
TOTAL              106     4879.2

MULTIPLE R= .94357  R-SQR= .89033  SE= 2.3368

    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT      SIGNIF

    CONSTANT                  44.052      4.9989      8.8122       .0000
  22.VDHP         -.41315   -.84021       .18708     -4.4912       .0000
  23.DISP         -.29118   -.30671 -1    .10179 -1  -3.0131       .0033
  24.RTHP         -.28220   -.53817 -1    .18481 -1  -2.9120       .0044
  27.NSVR         -.59512   -.33982       .46354 -1  -7.3309       .0000
  40.ETWM1         .65727    65543.       7591.8      8.6334       .0000
```

```
   1.FTPHC           .22901   7.9291      3.4045      2.3290       .0219
   2.FTPCO          -.36117  -1.4245       .37152    -3.8342       .0002
   3.FTPNOX          .19301   1.6148       .82926     1.9473       .0544

    REMAINING       PARTIAL   SIGNIF

   4.FEHC            .10978    .2794
   5.FECO            .04036    .6917
   6.FENOX          -.00460    .9639

REGRESSION OF 12.HMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR       VARIABLE          PARTIAL  SIGNIF

   0   .89193    2.3560      11                       IN
   1   .89189    2.3441      10      6.FENOX         OUT  -.01944   .8501
   2   .89165    2.3346       9      5.FECO          OUT  -.04699   .6459
   3   .89033    2.3368       8      4.FEHC          OUT   .10978   .2794
```

```
<SELECT RYST OPTIONS=STEPWISE BACKWARD VAR=1[illegible]-24 [illegible]0,1[illegible]AXI[illegible]STR[illegible]50:8[illegible]6:([illegible]0-1[illegible]28:([illegible])>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(LA,LA)


ANALYSIS AT STEP 0 FOR 12.HMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            11    356.91       32.446       19.638      .0000
ERROR                 51    84.263       1.6522
TOTAL                 62    441.17

MULTIPLE R= .89945  R-SQR= .80900  SE= 1.2854

    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

    CONSTANT                 31.939      4.4799      7.1294     .0000
 22.VDHP          -.17840   -.21369      .16504     -1.2948     .2012
 23.DISP          -.53207   -.36762 -1   .81917 -2  -4.4877     .0000
 24.RTHP           .01744    .15158 -2   .12166 -1   .12459     .9013
 27.NSVR          -.64928   -.32977      .54091 -1  -6.0967     .0000
 40.ETWM1          .58755   58597.       11300.      5.1853     .0000
  1.FTPHC         -.08297   -2.4008      4.0378     -.59458     .5548
  2.FTPCO         -.04978   -.75358 -1   .21172     -.35593     .7234
  3.FTPNOX         .42458    3.9751      1.1870      3.3490     .0015
  4.FEHC          -.02540   -2.0584      11.344     -.18144     .8567
  5.FECO           .05296    .15119      .39922      .37872     .7065
  6.FENOX         -.30684   -2.0202      .87748     -2.3023     .0254



ANALYSIS AT STEP 1 FOR 12.HMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            10    356.89       35.689       22.017      .0000
ERROR                 52    84.288       1.6209
TOTAL                 62    441.17

MULTIPLE R= .89941  R-SQR= .80895  SE= 1.2732

    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

    CONSTANT                 31.963      4.4334      7.2095     .0000
 22.VDHP          -.18310   -.21688      .16149     -1.3430     .1851
 23.DISP          -.65045   -.36053 -1   .58383 -2  -6.1753     .0000
 27.NSVR          -.66160   -.32794      .51543 -1  -6.3623     .0000
 40.ETWM1          .58863   58450.       11132.      5.2507     .0000
  1.FTPHC         -.08122   -2.3180      3.9448     -.58760     .5593
  2.FTPCO         -.05301   -.79355 -1   .20729     -.38282     .7034
  3.FTPNOX         .42457    3.9637      1.1722      3.3815     .0014
  4.FEHC          -.02643   -2.1387      11.218     -.19064     .8495
  5.FECO           .05396    .15387      .39486      .38968     .6984
  6.FENOX         -.30767   -2.0248      .86837     -2.3317     .0236

    REMAINING      PARTIAL   SIGNIF
  24.RTHP              .01744     .9013


ANALYSIS AT STEP 2 FOR 12.HMPG  N= 63 OUT OF 140

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION               9    356.83       39.647       24.913      .0000
ERROR                   53    84.347       1.5915
TOTAL                   62    441.17

MULTIPLE R= .89934  R-SQR= .80881  SE= 1.2615

    VARIABLE         PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

    CONSTANT                    32.159      4.2733      7.5254      .0000
 22.VDHP            -.19268   -.22346       .15632     -1.4295      .1587
 23.DISP            -.65107   -.36098 -1    .57804 -2  -6.2448      .0000
 27.NSVR            -.66812   -.32952       .50407 -1  -6.5372      .0000
 40.ETWM1            .58944    58206.      10957.       5.3121      .0000
   1.FTPHC          -.12127   -2.7719      3.1166      -.88939      .3778
   2.FTPCO          -.04618   -.62622 -1    .18607     -.33654      .7378
   3.FTPNOX          .42398    3.9563      1.1608       3.4081      .0013
   5.FECO            .06588    .87164 -1    .18133      .48069      .6327
   6.FENOX          -.31065   -2.0393       .85712     -2.3793      .0210

   REMAINING         PARTIAL   SIGNIF

  24.RTHP            .01891     .8920
   4.FEHC           -.02643     .8495


ANALYSIS AT STEP 3 FOR 12.HMPG  N= 63 OUT OF 140

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION               8    356.65       44.581       28.480      .0000
ERROR                   54    84.528       1.5653
TOTAL                   62    441.17

MULTIPLE R= .89911  R-SQR= .80840  SE= 1.2511

    VARIABLE         PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

    CONSTANT                    32.145      4.2379      7.5850      .0000
 22.VDHP            -.21757   -.24040       .14677     -1.6380      .1072
 23.DISP            -.65496   -.35686 -1    .56029 -2  -6.3692      .0000
 27.NSVR            -.67943   -.33299       .48935 -1  -6.8046      .0000
 40.ETWM1            .59567    58696.      10771.       5.4496      .0000
   1.FTPHC          -.16087   -3.2658      2.7267      -1.1977      .2362
   3.FTPNOX            .42813    3.9915        1.1466      3.4813      .0010
   5.FECO              .05159     .62401 -1     .16437      .37965     .7057
   6.FENOX            -.30754   -2.0013         .84266    -2.3750      .0211

     REMAINING       PARTIAL    SIGNIF

  24.RTHP              .02521     .8550
   2.FTPCO            -.04618     .7378
   4.FEHC             -.00436     .9748



ANALYSIS AT STEP 4 FOR 12.HMPG  N= 63 OUT OF 140

SOURCE               DF    SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

REGRESSION            7      356.42        50.917      33.042       .0000
ERROR                55      84.753        1.5410
TOTAL                62      441.17

MULTIPLE R= .89883  R-SQR= .80789  SE= 1.2414

     VARIABLE        PARTIAL   COEFFICIENT   STD ERROR    T-STAT      SIGNIF

     CONSTANT                    32.025       4.1931      7.6374      .0000
  22.VDHP            -.21164   -.22778        .14183     -1.6060      .1140
  23.DISP            -.65465   -.35703 -1     .55589 -2  -6.4226      .0000
  27.NSVR            -.67970   -.33353        .48532 -1  -6.8723      .0000
  40.ETWM1            .59597    58800.       10683.       5.5041      .0000
   1.FTPHC           -.15507   -3.1162       2.6770      -1.1641      .2494
   3.FTPNOX           .42824    3.9977       1.1375       3.5145      .0009
   6.FENOX           -.32318   -2.0693        .81702     -2.5327      .0142

     REMAINING       PARTIAL    SIGNIF

  24.RTHP             .02232     .8703
   2.FTPCO           -.02121     .8767
   4.FEHC             .04232     .7568
   5.FECO             .05159     .7057



ANALYSIS AT STEP 5 FOR 12.HMPG  N= 63 OUT OF 140

SOURCE               DF    SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

REGRESSION            6      354.33        59.055      38.082       .0000
ERROR                56      86.841        1.5507
TOTAL                62      441.17

MULTIPLE R= .89619  R-SQR= .80316  SE= 1.2453
```

```
      VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

      CONSTANT                  31.518      4.1837       7.5336     .0000
   22.VDHP           -.22238   -.24196       .14175     -1.7069     .0934
   23.DISP           -.65776   -.36291  -1   .55534 -2  -6.5348     .0000
   27.NSVR           -.67038   -.32112       .47497 -1  -6.7609     .0000
   40.ETWM1           .58331    56954.      10598.       5.3740     .0000
    3.FTPNOX          .45547    4.2732      1.1161       3.8287     .0003
    6.FENOX          -.31133   -2.0047       .81771     -2.4516     .0174

      REMAINING       PARTIAL    SIGNIF

   24.RTHP            .00589     .9653
    1.FTPHC          -.15507     .2494
    2.FTPCO          -.09332     .4899
    4.FEHC           -.01982     .8836
    5.FECO            .02803     .8361

REGRESSION OF 12.HMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR      VARIABLE          PARTIAL  SIGNIF

  0    .80900   1.2854      11                     IN
  1    .80895   1.2732      10    24.RTHP         OUT    .01744   .9013
  2    .80881   1.2615       9     4.FEHC         OUT  -.02643   .8495
  3    .80840   1.2511       8     2.FTPCO        OUT  -.04618   .7378
  4    .80789   1.2414       7     5.FECO         OUT    .05159   .7057
  5    .80316   1.2453       6     1.FTPHC        OUT  -.15507   .2494
```

```
<SELECT.RYST OPTIONS=STEPWISE,BACKWARD VAR=13,22-24,27,40,1-6 MAXIM=10 STRAT=[illegible]:81*[illegible]:(1-7,10-17)>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)

ANALYSIS AT STEP 0 FOR 13.CMPG  N= 267 OUT OF 571

SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

REGRESSION          11    9737.7       885.24       215.73    0.
ERROR              255    1046.4       4.1034
TOTAL              266    10784.

MULTIPLE R= .95025  R-SQR= .90297  SE= 2.0257

     VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

     CONSTANT                  12.846       2.7572       4.6590     .0000
  22.VDHP           .04181     .63800 -1    .95466 -1    .66830     .5045
  23.DISP          -.16464    -.10959 -1    .41113 -2   -2.6655     .0082
  24.RTHP          -.25403    -.33358 -1    .79534 -2   -4.1942     .0000
  27.NSVR          -.50098    -.21120       .22848 -1   -9.2436     .0000
  40.ETWM1          .71945     76745.       4639.6       16.541     .0000
   1.FTPHC          .11483     3.7707       2.0428       1.8458     .0661
   2.FTPCO         -.17649    -.37671       .13157      -2.8633     .0045
   3.FTPNOX         .14693     1.7999       .75878       2.3721     .0184
   4.FEHC          -.02068    -1.4159       4.2869      -.33029     .7414
   5.FECO          -.01949    -.60926 -1    .19570      -.31132     .7558
   6.FENOX         -.07647    -.64243       .52453      -1.2248     .2218


ANALYSIS AT STEP 1 FOR 13.CMPG  N= 267 OUT OF 571

SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

REGRESSION          10    9737.3       973.73       238.14    0.
ERROR              256    1046.8       4.0889
TOTAL              266    10784.

MULTIPLE R= .95023  R-SQR= .90293  SE= 2.0221

     VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

     CONSTANT                  12.854       2.7522       4.6705     .0000
  22.VDHP           .04046     .61561 -1    .95027 -1    .64783     .5177
  23.DISP          -.16410    -.10918 -1    .41020 -2   -2.6616     .0083
  24.RTHP          -.25378    -.33326 -1    .79387 -2   -4.1979     .0000
  27.NSVR          -.50254    -.21167       .22759 -1   -9.3004     .0000
  40.ETWM1          .71986     76798.       4628.2       16.593     .0000
   1.FTPHC          .12391     3.9353       1.9697       1.9979     .0468
   2.FTPCO         -.19264    -.39005       .12418      -3.1410     .0019
   3.FTPNOX         .14656     1.7952       .75729       2.3705     .0185
   4.FEHC          -.04244    -2.2574       3.3216      -.67962     .4974
   6.FENOX         -.07445    -.61904       .51820      -1.1946     .2334

     REMAINING      PARTIAL    SIGNIF
     5.FECO              -.01949     .7558



   ANALYSIS AT STEP 2 FOR 13.CMPG  N= 267 OUT OF 571

   SOURCE                  DF    SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

   REGRESSION               9     9735.5        1081.7       265.15      0.
   ERROR                  257     1048.5        4.0797
   TOTAL                  266     10784.

   MULTIPLE R= .95014  R-SQR= .90277  SE= 2.0198

        VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT       SIGNIF

        CONSTANT                    13.846      2.2845      6.0606       .0000
     23.DISP          -.16016   -.10562 -1    .40604 -2   -2.6012       .0098
     24.RTHP          -.26667   -.34399 -1    .77552 -2   -4.4356       .0000
     27.NSVR          -.50314   -.20921       .22415 -1   -9.3335       .0000
     40.ETWM1          .74987    75482.       4154.1       18.171       .0000
      1.FTPHC          .12288    3.9042       1.9669       1.9850       .0482
      2.FTPCO         -.19536   -.39526       .12378      -3.1934       .0016
      3.FTPNOX         .14268    1.7349       .75069       2.3110       .0216
      4.FEHC          -.03878   -2.0548       3.3031      -.62208       .5344
      6.FENOX         -.07030   -.58102       .51429      -1.1298       .2596

        REMAINING      PARTIAL    SIGNIF

     22.VDHP           .04046     .5177
      5.FECO          -.01637     .7935



   ANALYSIS AT STEP 3 FOR 13.CMPG  N= 267 OUT OF 571

   SOURCE                  DF    SUM OF SQRS  MEAN SQUARE    F-STAT      SIGNIF

   REGRESSION               8     9734.0        1216.7       298.96      0.
   ERROR                  258     1050.1        4.0700
   TOTAL                  266     10784.

   MULTIPLE R= .95007  R-SQR= .90263  SE= 2.0174

        VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT       SIGNIF

        CONSTANT                    13.837      2.2818      6.0641       .0000
     23.DISP          -.16067   -.10603 -1    .40550 -2   -2.6147       .0095
     24.RTHP          -.27020   -.34798 -1    .77195 -2   -4.5078       .0000
     27.NSVR          -.50351   -.20952       .22382 -1   -9.3608       .0000
     40.ETWM1          .74958    75470.       4149.1       18.189       .0000
      1.FTPHC          .11796    3.6911       1.9345       1.9081       .0575
```

```
  2.FTPCO          -.19870  -.40134       .12324     -3.2565       .0013
  3.FTPNOX          .14910   1.7988       .74273      2.4219       .0161
  6.FENOX          -.06934  -.57330       .51353     -1.1164       .2653

    REMAINING      PARTIAL   SIGNIF

 22.VDHP            .03659    .5577
  4.FEHC           -.03878    .5344
  5.FECO           -.03725    .5507



ANALYSIS AT STEP 4 FOR 13.CMPG  N= 267 OUT OF 571

SOURCE              DF    SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           7     9728.9       1389.8       341.16      0.
ERROR              259     1055.1       4.0739
TOTAL              266     10784.

MULTIPLE R= .94982  R-SQR= .90216  SE= 2.0184


    VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

    CONSTANT                 14.245      2.2534      6.3213      .0000
 23.DISP           -.17055  -.11202 -1   .40213 -2  -2.7856      .0057
 24.RTHP           -.26625  -.34266 -1   .77084 -2  -4.4453      .0000
 27.NSVR           -.50353  -.20999      .22389 -1  -9.3794      .0000
 40.ETWM1           .74982   74727.      4097.3     18.238       .0000
  1.FTPHC           .10722   3.3048      1.9042      1.7355      .0838
  2.FTPCO          -.18947  -.37673      .12131     -3.1054      .0021
  3.FTPNOX          .14139   1.2171      .52952      2.2985      .0223

    REMAINING      PARTIAL   SIGNIF

 22.VDHP            .02862    .6460
  4.FEHC           -.03700    .5526
  5.FECO           -.02856    .6467
  6.FENOX          -.06934    .2653

REGRESSION OF 13.CMPG USING BACKWARD SELECTION

STEP  . R-SQR  STD ERROR  # VAR       VARIABLE        PARTIAL  SIGNIF

   0   .90297   2.0257      11                     IN
   1   .90293   2.0221      10      5.FECO        OUT  -.01949   .7558
   2   .90277   2.0198       9     22.VDHP        OUT   .04046   .5177
   3   .90263   2.0174       8      4.FEHC        OUT  -.03878   .5344
   4   .90216   2.0184       7      6.FENOX       OUT  -.06934   .2653
```

```
<SELECT BYST OPTIONS=STEPWISE,BACKWARD VAR=13;22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V36:(1-7,10-17)*V28:(1,6,8)>

SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(CA,CA,CA)


ANALYSIS AT STEP 0 FOR 13.CMPG  N= 97 OUT OF 198

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              11    1877.7        170.70      70.442      .0000
ERROR                   85    205.98        2.4233
TOTAL                   96    2083.7

MULTIPLE R= .94929  R-SQR= .90115  SE= 1.5567

     VARIABLE        PARTIAL  COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                  19.672      3.8656       5.0889      .0000
   22.VDHP          -.12158   -.14743       .13055     -1.1293      .2619
   23.DISP          -.24191   -.11594 -1    .50440 -2  -2.2986      .0240
   24.RTHP          -.34440   -.32199 -1    .95204 -2  -3.3821      .0011
   27.NSVR          -.30931   -.93025 -1    .31022 -1  -2.9987      .0036
   40.ETWM1          .55216    46767.      7659.3       6.1059      .0000
    1.FTPHC         -.05445   -1.5416      3.0663      -.50275      .6164
    2.FTPCO          .08697    .12902       .16030      .80490      .4231
    3.FTPNOX        -.07065   -.73025      1.1183      -.65298      .5155
    4.FEHC           .03777    1.3828      3.9680       .34849      .7283
    5.FECO          -.10772   -.18020       .18039     -.99897      .3206
    6.FENOX         -.04163   -.28529       .74262     -.38417      .7018



ANALYSIS AT STEP 1 FOR 13.CMPG  N= 97 OUT OF 198

SOURCE                  DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION              10    1877.4        187.74      78.274      .0000
ERROR                   86    206.27        2.3985
TOTAL                   96    2083.7

MULTIPLE R= .94921  R-SQR= .90101  SE= 1.5487

     VARIABLE        PARTIAL  COEFFICIENT  STD ERROR    T-STAT      SIGNIF

     CONSTANT                  19.749      3.8395       5.1438      .0000
   22.VDHP          -.12516   -.15137       .12939     -1.1698      .2453
   23.DISP          -.24070   -.11534 -1    .50152 -2  -2.2998      .0239
   24.RTHP          -.34342   -.32105 -1    .94679 -2  -3.3909      .0011
   27.NSVR          -.31140   -.93639 -1    .30813 -1  -3.0389      .0031
   40.ETWM1          .55223    46804.      7619.4       6.1427      .0000
    1.FTPHC         -.04651   -1.2757      2.9547      -.43177      .6670
    2.FTPCO          .08278    .12182       .15815      .77030      .4432
    3.FTPNOX        -.07679   -.78639      1.1010      -.71425      .4770
    5.FECO          -.10331   -.14731       .15293     -.96320      .3381
    6.FENOX         -.04338   -.29715       .73804     -.40262      .6882

     REMAINING       PARTIAL   SIGNIF
   4.FEHC             .03777    .7283



 ANALYSIS AT STEP 2 FOR 13.CMPG  N= 97 OUT OF 198

 SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

 REGRESSION            9     1877.0       208.56      87.799      .0000
 ERROR                87     206.66       2.3754
 TOTAL                96     2083.7

 MULTIPLE R= .94912  R-SQR= .90082  SE= 1.5412

     VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                   19.788      3.8197     5.1806      .0000
   22.VDHP          -.12342   -.14925       .12866    -1.1601      .2492
   23.DISP          -.25389   -.11953 -1    .48822 -2 -2.4484      .0164
   24.RTHP          -.34468   -.31080 -1    .90748 -2 -3.4248      .0009
   27.NSVR          -.30992   -.93165 -1    .30642 -1 -3.0404      .0031
   40.ETWM1          .55106    46632.       7570.6     6.1595      .0000
    1.FTPHC         -.06833   -1.7337       2.7138    -.63884      .5246
    2.FTPCO          .09470    .13609       .15338     .88730      .3774
    3.FTPNOX        -.12286   -1.0392       .89998    -1.1547      .2514
    5.FECO          -.09622   -.13398       .14859    -.90168      .3697

     REMAINING       PARTIAL   SIGNIF

    4.FEHC           .03969     .7135
    6.FENOX         -.04338     .6882



 ANALYSIS AT STEP 3 FOR 13.CMPG  N= 97 OUT OF 198

 SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

 REGRESSION            8     1876.1       234.51      99.391      .0000
 ERROR                88     207.63       2.3594
 TOTAL                96     2083.7

 MULTIPLE R= .94887  R-SQR= .90035  SE= 1.5360

     VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                   19.724      3.8055     5.1829      .0000
   22.VDHP          -.12688   -.15364       .12804    -1.1999      .2334
   23.DISP          -.26416   -.12383 -1    .48194 -2 -2.5693      .0119
   24.RTHP          -.35548   -.31923 -1    .89479 -2 -3.5677      .0006
   27.NSVR          -.31217   -.94040 -1    .30508 -1 -3.0825      .0027
   40.ETWM1          .55312    46913.       7532.3     6.2282      .0000
```

```
  2.FTPCO          .06705    .76497 -1    .12134     .63045      .5300
  3.FTPNOX        -.12613   -1.0684       .89579    -1.1927      .2362
  5.FECO          -.08766   -.12113       .14672    -.82555      .4113

   REMAINING       PARTIAL   SIGNIF

  1.FTPHC         -.06833    .5246
  4.FEHC           .02120    .8436
  6.FENOX         -.06624    .5374


ANALYSIS AT STEP 4 FOR 13.CMPG  N= 97 OUT OF 198

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

REGRESSION            7    1875.1       267.87       114.31     .0000
ERROR                89    208.57       2.3435
TOTAL                96    2083.7

MULTIPLE R= .94863  R-SQR= .89990  SE= 1.5308

   VARIABLE        PARTIAL  COEFFICIENT  STD ERROR   T-STAT    SIGNIF

   CONSTANT                  19.882      3.7844      5.2536     .0000
 22.VDHP          -.14152   -.16897      .12529     -1.3486     .1809
 23.DISP          -.27031   -.12666 -1   .47821 -2  -2.6487     .0096
 24.RTHP          -.34996   -.31054 -1   .88111 -2  -3.5244     .0007
 27.NSVR          -.30920   -.93164 -1   .30373 -1  -3.0673     .0029
 40.ETWM1          .55162    46827.      7505.6      6.2390     .0000
  3.FTPNOX        -.11132   -.90099      .85260     -1.0567     .2935
  5.FECO          -.07401   -.99558 -1   .14220     -.70015     .4857

   REMAINING       PARTIAL   SIGNIF

  1.FTPHC         -.01333    .9007
  2.FTPCO          .06705    .5300
  4.FEHC           .02397    .8225
  6.FENOX         -.06422    .5476


ANALYSIS AT STEP 5 FOR 13.CMPG  N= 97 OUT OF 198

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT    SIGNIF

REGRESSION            6    1874.0       312.33       134.04     .0000 .
ERROR                90    209.72       2.3302
TOTAL                96    2083.7

MULTIPLE R= .94834  R-SQR= .89935  SE= 1.5265
```

```
      VARIABLE         PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

      CONSTANT                   19.667      3.7613      5.2289      .0000
   22.VDHP            -.13711  -.16377      .12471     -1.3131      .1925
   23.DISP            -.26566  -.12437 -1   .47573 -2  -2.6142      .0105
   24.RTHP            -.35376  -.31458 -1   .87674 -2  -3.5880      .0005
   27.NSVR            -.31712  -.95496 -1   .30104 -1  -3.1722      .0021
   40.ETWM1            .55544   47263.      7458.5      6.3367      .0000
    3.FTPNOX          -.09838  -.78113      .83287     -.93788      .3508

      REMAINING        PARTIAL   SIGNIF

    1.FTPHC           -.01583    .8816
    2.FTPCO            .04777    .6530
    4.FEHC            -.01845    .8622
    5.FECO            -.07401    .4857
    6.FENOX           -.04338    .6831


ANALYSIS AT STEP 6 FOR 13.CMPG  N= 97 OUT OF 198

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT      SIGNIF

REGRESSION              5    1871.9       374.38       160.88      .0000
ERROR                  91    211.77       2.3271
TOTAL                  96    2083.7

MULTIPLE R= .94782  R-SQR= .89837  SE= 1.5255

      VARIABLE         PARTIAL  COEFFICIENT  STD ERROR   T-STAT      SIGNIF

      CONSTANT                   19.267      3.7346      5.1592      .0000
   22.VDHP            -.11880  -.13903      .12181     -1.1414      .2567
   23.DISP            -.29970  -.13681 -1   .45654 -2  -2.9967      .0035
   24.RTHP            -.34633  -.30738 -1   .87279 -2  -3.5218      .0007
   27.NSVR            -.30891  -.92781 -1   .29945 -1  -3.0984      .0026
   40.ETWM1            .54998   46630.      7423.1      6.2818      .0000

      REMAINING        PARTIAL   SIGNIF

    1.FTPHC           -.03729    .7241
    2.FTPCO            .02121    .8409
    3.FTPNOX          -.09838    .3508
    4.FEHC             .00778    .9413
    5.FECO            -.05240    .6198
    6.FENOX           -.09336    .3761


ANALYSIS AT STEP 7 FOR 13.CMPG  N= 97 OUT OF 198

SOURCE                 DF   SUM OF SQRS  MEAN SQUARE   F-STAT      SIGNIF
```

```
REGRESSION            4     1868.9       467.22       200.11      .0000
ERROR                92     214.80       2.3348
TOTAL                96     2083.7

MULTIPLE R= .94706  R-SQR= .89691  SE= 1.5280

    VARIABLE       PARTIAL   COEFFICIENT  STD ERROR    T-STAT    SIGNIF

    CONSTANT                   16.825     3.0660       5.4877     .0000
  23.DISP          -.30758   -.14127 -1   .45562 -2   -3.1006     .0026
  24.RTHP          -.32870   -.28289 -1   .84740 -2   -3.3383     .0012
  27.NSVR          -.37588   -.10665      .27412 -1   -3.8907     .0002
  40.ETWM1          .65551    51360.      6168.8       8.3257     .0000

    REMAINING      PARTIAL   SIGNIF

  22.VDHP          -.11880    .2567
   1.FTPHC         -.02205    .8338
   2.FTPCO          .04974    .6359
   3.FTPNOX        -.07035    .5028
   4.FEHC           .01256    .9049
   5.FECO          -.05011    .6334
   6.FENOX         -.07598    .4691

REGRESSION OF 13.CMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR      VARIABLE         PARTIAL  SIGNIF

  0    .90115   1.5567       11                   IN
  1    .90101   1.5487       10      4.FEHC      OUT   .03777   .7283
  2    .90082   1.5412        9      6.FENOX     OUT  -.04338   .6882
  3    .90035   1.5360        8      1.FTPHC     OUT  -.06833   .5246
  4    .89990   1.5308        7      2.FTPCO     OUT   .06705   .5300
  5    .89935   1.5265        6      5.FECO      OUT  -.07401   .4857
  6    .89837   1.5255        5      3.FTPNOX    OUT  -.09838   .3508
  7    .89691   1.5280        4     22.VDHP      OUT  -.11880   .2567
```

```
<SELECT RYST OPTIONS=STEPWISE BACKWARD VAR=13:22-24,27,40,1-6 MAXIM=10 STRAT=V50:81*V26:(1-7,10-17)*V28:(2,3,4)>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(CM,CM,CM)

ANALYSIS AT STEP 0 FOR 13.CMPG  N= 107 OUT OF 233

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           11    3653.6       332.14       82.251      .0000
ERROR                95    383.63       4.0382
TOTAL               106    4037.2

MULTIPLE R= .95130  R-SQR= .90498  SE= 2.0095

     VARIABLE       PARTIAL   COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                  18.457       4.5545      4.0526     .0001
  22.VDHP         -.03677   -.60782 -1    .16950     -.35860     .7207
  23.DISP         -.03389   -.29388 -2    .88912 -2  -.33053     .7417
  24.RTHP         -.40202   -.71897 -1    .16800 -1  -4.2795     .0000
  27.NSVR         -.41240   -.17876       .40515 -1  -4.4122     .0000
  40.ETWM1         .72318    71372.       6993.3      10.206     .0000
   1.FTPHC         .20501    6.8956       3.3777      2.0415     .0440
   2.FTPCO        -.36316   -1.3193       .34727     -3.7990     .0003
   3.FTPNOX        .08948    1.0554       1.2053      .87561     .3835
   4.FEHC          .03225    3.5110       11.164      .31449     .7538
   5.FECO         -.02194   -.19029       .88960     -.21390     .8311
   6.FENOX         .02807    .21949       .80205      .27366     .7849



ANALYSIS AT STEP 1 FOR 13.CMPG  N= 107 OUT OF 233

SOURCE               DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           10    3653.4       365.34       91.380      .0000
ERROR                96    383.81       3.9980
TOTAL               106    4037.2

MULTIPLE R= .95128  R-SQR= .90493  SE= 1.9995

     VARIABLE       PARTIAL   COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                  18.403       4.5248      4.0672     .0001
  22.VDHP         -.03663   -.60561 -1    .16865     -.35909     .7203
  23.DISP         -.03058   -.26124 -2    .87156 -2  -.29974     .7650
  24.RTHP         -.40576   -.72287 -1    .16618 -1  -4.3498     .0000
  27.NSVR         -.41646   -.17975       .40050 -1  -4.4881     .0000
  40.ETWM1         .72592    71534.       6917.4      10.341     .0000
   1.FTPHC         .23488    7.2027       3.0422      2.3676     .0199
   2.FTPCO        -.39671   -1.3482       .31838     -4.2344     .0001
   3.FTPNOX        .09352    1.0924       1.1869      .92036     .3597
   4.FEHC          .02364    1.8822       8.1235      .23170     .8173
   6.FENOX         .02988    .23300       .79558      .29286     .7703

     REMAINING      PARTIAL   SIGNIF
     5.FECO          -.02194     .8311


ANALYSIS AT STEP 2 FOR 13.CMPG  N= 107 OUT OF 233

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             9     3653.2       405.91      102.53      .0000
ERROR                 97     384.03       3.9590
TOTAL                106     4037.2

MULTIPLE R= .95125  R-SQR= .90488  SE= 1.9897

    VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

    CONSTANT                    18.182      4.4011      4.1312      .0001
  22.VDHP         -.03244    -.52487 -1    .16420     -.31964      .7499
  23.DISP         -.02975    -.25408 -2    .86675 -2  -.29314      .7700
  24.RTHP         -.41477    -.71195 -1    .15859 -1  -4.4894      .0000
  27.NSVR         -.42183    -.18099       .39498 -1  -4.5822      .0000
  40.ETWM1         .73893     71939.       6660.3      10.801      .0000
   1.FTPHC         .25083     7.4040       2.9012      2.5520      .0123
   2.FTPCO        -.39736    -1.3505       .31666     -4.2647      .0000
   3.FTPNOX        .09084     1.0455       1.1638      .89834      .3712
   6.FENOX         .03237     .25128       .78779      .31897      .7504

   REMAINING       PARTIAL   SIGNIF

   4.FEHC          .02364     .8173
   5.FECO          .00008     .9993


ANALYSIS AT STEP 3 FOR 13.CMPG  N= 107 OUT OF 233

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             8     3652.8       456.60      116.42      .0000
ERROR                 98     384.37       3.922
TOTAL                106     4037.2

MULTIPLE R= .95121  R-SQR= .90479  SE= 1.9804

    VARIABLE       PARTIAL   COEFFICIENT   STD ERROR    T-STAT     SIGNIF

    CONSTANT                    17.731      4.1038      4.3206      .0000
  22.VDHP         -.02856    -.45777 -1    .16184     -.28285      .7779
  24.RTHP         -.49095    -.73737 -1    .13217 -1  -5.5787      .0000
  27.NSVR         -.42651    -.17823       .38179 -1  -4.6681      .0000
  40.ETWM1         .75404     72472.       6376.9      11.365      .0000
   1.FTPHC         .25346     7.4686       2.8794      2.5938      .0109
  2.FTPCO          -.39790  -1.3528      .31509     -4.2935      .0000
  3.FTPNOX          .08672   .97927     1.1363       .86178      .3909
  6.FENOX           .03244   .25192      .78410      .32129      .7487

   REMAINING       PARTIAL   SIGNIF

 23.DISP           -.02975    .7700
  4.FEHC            .02256    .8246
  5.FECO            .00314    .9754


ANALYSIS AT STEP 4 FOR 13.CMPG  N= 107 OUT OF 233

SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           7     3652.5       521.79      134.29      .0000
ERROR               99     384.68       3.8857
TOTAL              106     4037.2

MULTIPLE R= .95117  R-SQR= .90472  SE= 1.9712

   VARIABLE        PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

   CONSTANT                  17.111      3.4553       4.9523      .0000
 24.RTHP           -.49178  -.73219 -1   .13029 -1   -5.6197      .0000
 27.NSVR           -.45033  -.18153      .36174 -1   -5.0184      .0000
 40.ETWM1           .79251   73284.      5667.8       12.930      .0000
  1.FTPHC           .25353   7.4736      2.8659       2.6078      .0105
  2.FTPCO          -.39719  -1.3496      .31342      -4.3062      .0000
  3.FTPNOX          .09545   1.0515      1.1021       .95404      .3424
  6.FENOX           .02623   .19750      .75659       .26104      .7946

   REMAINING       PARTIAL   SIGNIF

 22.VDHP           -.02856    .7779
 23.DISP           -.02547    .8014
  4.FEHC            .01626    .8724
  5.FECO           -.00126    .9901


ANALYSIS AT STEP 5 FOR 13.CMPG  N= 107 OUT OF 233

SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION           6     3652.3       608.71      158.13      .0000
ERROR              100     384.94       3.8494
TOTAL              106     4037.2

MULTIPLE R= .95113  R-SQR= .90465  SE= 1.9620
```

```
   VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

   CONSTANT                  16.956      3.3876     5.0053      .0000
24.RTHP          -.49219   -.72821 -1    .12879 -1 -5.6541      .0000
27.NSVR          -.44974   -.18115       .35976 -1 -5.0354      .0000
40.ETWM1          .79728   73525.        5566.4     13.209      .0000
 1.FTPHC          .25265   7.4416        2.8499     2.6112      .0104
 2.FTPCO         -.39871   -1.3542       .31148    -4.3476      .0000
 3.FTPNOX         .19063   1.2813        .65981     1.9419      .0550

   REMAINING      PARTIAL   SIGNIF

22.VDHP          -.02124     .8330
23.DISP          -.02644     .7930
 4.FEHC           .02001     .8426
 5.FECO           .00003     .9998
 6.FENOX          .02623     .7946

REGRESSION OF 13.CMPG USING BACKWARD SELECTION

STEP    R-SQR   STD ERROR  # VAR      VARIABLE          PARTIAL  SIGNIF

  0    .90498   2.0095       11                     IN
  1    .90493   1.9995       10       5.FECO       OUT  -.02194    .8311
  2    .90488   1.9897        9       4.FEHC       OUT   .02364    .8173
  3    .90479   1.9804        8      23.DISP       OUT  -.02975    .7700
  4    .90472   1.9712        7      22.VDHP       OUT  -.02856    .7779
  5    .90465   1.9620        6       6.FENOX      OUT   .02623    .7946
```

```
<SELECT BYST OPTIONS=STEPWISE,BACKWARD VAR=13:22-24,27.40,1-6 MAXIM=10 STRAT=V50:81*V36:(1-7 10-17)*V28:(7 9)>
SELECTION OF REGRESSION  <1> TAYR:81*FTYP:(1-7,10-17)*VTRN:(LA,LA)


ANALYSIS AT STEP 0 FOR 13.CMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            11    327.39        29.763       43.378      .0000
ERROR                 51    34.993        .68613
TOTAL                 62    362.38

MULTIPLE R= .95049  R-SQR= .90344  SE= .82833

    VARIABLE      PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

    CONSTANT                 24.839      2.8870     8.6037      .0000
 22.VDHP         -.21717   -.16898       .10635    -1.5889      .1183
 23.DISP         -.61911   -.29721 -1    .52789 -2 -5.6301      .0000
 24.RTHP         -.09230   -.51900 -2    .78403 -2  -.66196     .5110
 27.NSVR         -.46373   -.13029       .34857 -1 -3.7379      .0005
 40.ETWM1         .58291    37309.       7282.3     5.1232      .0000
  1.FTPHC        -.21616   -4.1140       2.6020    -1.5811      .1200
  2.FTPCO         .06556    .64020 -1    .13644     .46922     .6409
  3.FTPNOX        .46436    2.8641       .76492     3.7443      .0005
  4.FEHC          .05379    2.8121       7.3105     .38466     .7021
  5.FECO         -.06678   -.12296       .25727    -.47794     .6347
  6.FENOX        -.35605   -1.5387       .56547    -2.7211      .0089



ANALYSIS AT STEP 1 FOR 13.CMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION            10    327.29        32.729       48.496      .0000
ERROR                 52    35.094        .67489
TOTAL                 62    362.38

MULTIPLE R= .95035  R-SQR= .90316  SE= .82151

    VARIABLE      PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

    CONSTANT                 24.585      2.7872     8.8204      .0000
 22.VDHP         -.21089   -.16072       .10331    -1.5558      .1258
 23.DISP         -.61767   -.29583 -1    .52234 -2 -5.6636      .0000
 24.RTHP         -.09533   -.53614 -2    .77633 -2  -.69061     .4929
 27.NSVR         -.46212   -.12801       .34067 -1 -3.7577      .0004
 40.ETWM1         .58772    37611.       7180.1     5.2382      .0000
  1.FTPHC        -.23022   -3.5097       2.0573    -1.7060      .0940
  2.FTPCO         .04712    .41637 -1    .12239     .34019     .7351
  3.FTPNOX        .46506    2.8726       .75831     3.7882      .0004
  5.FECO         -.04134   -.35235 -1    .11809    -.29838     .7666
  6.FENOX        -.35298   -1.5202       .55878    -2.7205      .0088

    REMAINING     PARTIAL   SIGNIF
```

```
   4.FEHC           .05379    .7021



ANALYSIS AT STEP 2 FOR 13.CMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             9    327.23        36.359       54.816      .0000
ERROR                 53    35.154        .66329
TOTAL                 62    362.38

MULTIPLE R= .95026  R-SQR= .90299  SE= .81442

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

     CONSTANT                  24.645       2.7560      8.9423      .0000
  22.VDHP          -.21369   -.16274       .10219     -1.5925      .1172
  23.DISP          -.61889   -.29664 -1    .51714 -2  -5.7362      .0000
  24.RTHP          -.09555   -.53783 -2    .76961 -2  -.69884      .4877
  27.NSVR          -.46080   -.12692       .33578 -1  -3.7799      .0004
  40.ETWM1          .58684   37445.       7096.8       5.2764      .0000
   1.FTPHC         -.22779   -3.4638      2.0338      -1.7031      .0944
   2.FTPCO          .03329    .26929 -1   .11106       .24247      .8094
   3.FTPNOX         .46377    2.8613      .75082       3.8109      .0004
   6.FENOX         -.35098   -1.4971      .54863      -2.7288      .0086

     REMAINING      PARTIAL    SIGNIF

   4.FEHC          -.01178     .9326
   5.FECO          -.04134     .7666



ANALYSIS AT STEP 3 FOR 13.CMPG  N= 63 OUT OF 140

SOURCE                DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

REGRESSION             8    327.19        40.899       62.755      .0000
ERROR                 54    35.193        .65172
TOTAL                 62    362.38

MULTIPLE R= .95020  R-SQR= .90288  SE= .80729

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR    T-STAT     SIGNIF

     CONSTANT                  24.636       2.7316      9.0189      .0000
  22.VDHP          -.21559   -.15415       .95016 -1  -1.6224      .1105
  23.DISP          -.61950   -.29708 -1    .51229 -2  -5.7992      .0000
  24.RTHP          -.10160   -.56597 -2    .75415 -2  -.75047      .4562
  27.NSVR          -.46377   -.12523       .32554 -1  -3.8467      .0003
  40.ETWM1          .58748   37228.       6978.4       5.3348      .0000
```

```
   1.FTPHC            -.24279  -3.2191      1.7503     -1.8392       .0714
   3.FTPNOX            .46294   2.8454      .74138      3.8379       .0003
   6.FENOX            -.36384  -1.5253      .53141     -2.8704       .0058

     REMAINING        PARTIAL   SIGNIF

   2.FTPCO             .03329    .8094
   4.FEHC             -.00665    .9616
   5.FECO             -.02441    .8596



 ANALYSIS AT STEP 4 FOR 13.CMPG  N= 63 OUT OF 140

 SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

 REGRESSION           7     326.82       46.689      72.213      .0000
 ERROR               55     35.560       .64655
 TOTAL               62     362.38

 MULTIPLE R= .94967  R-SQR= .90187  SE= .80408

     VARIABLE       PARTIAL  COEFFICIENT  STD ERROR   T-STAT     SIGNIF

     CONSTANT                   24.516      2.7161      9.0262      .0000
  22.VDHP          -.19718   -.13703     .91870 -1  -1.4916      .1415
  23.DISP          -.77199   -.32432 -1  .36008 -2  -9.0070      .0000
  27.NSVR          -.49046   -.13121     .31437 -1  -4.1739      .0001
  40.ETWM1          .59225    37721.     6919.8      5.4511      .0000
   1.FTPHC         -.25245   -3.3551     1.7340     -1.9349      .0582
   3.FTPNOX         .46656    2.8823     .73680      3.9119      .0003
   6.FENOX         -.36084   -1.5185     .52922     -2.8694      .0058

     REMAINING      PARTIAL   SIGNIF

  24.RTHP          -.10160    .4562
   2.FTPCO          .04805    .7251
   4.FEHC          -.00227    .9868
   5.FECO          -.01871    .8911



 ANALYSIS AT STEP 5 FOR 13.CMPG  N= 63 OUT OF 140

 SOURCE              DF   SUM OF SQRS  MEAN SQUARE   F-STAT     SIGNIF

 REGRESSION           6     325.38       54.231      82.082      .0000
 ERROR               56     36.999       .66069
 TOTAL               62     362.38

 MULTIPLE R= .94758  R-SQR= .89790  SE= .81283
```

```
   VARIABLE        PARTIAL  COEFFICIENT  STD ERROR    T-STAT      SIGNIF

   CONSTANT                   22.276      2.2879      9.7365       .0000
 23.DISP           -.76145  -.31690 -1   .36050 -2  -8.7906       .0000
 27.NSVR           -.45810  -.11391      .29537 -1  -3.8566       .0003
 40.ETWM1           .58530   37787.      6995.0      5.4020       .0000
  1.FTPHC          -.26402  -3.5773      1.7464     -2.0484       .0452
  3.FTPNOX          .46634   2.9349      .74396      3.9450       .0002
  6.FENOX          -.37125  -1.5934      .53256     -2.9921       .0041

   REMAINING       PARTIAL   SIGNIF

 22.VDHP           -.19718    .1415
 24.RTHP           -.04935    .7154
  2.FTPCO          -.03185    .8141
  4.FEHC           -.04720    .7274
  5.FECO           -.06255    .6439

REGRESSION OF 13.CMPG USING BACKWARD SELECTION

STEP    R-SQR  STD ERROR  # VAR       VARIABLE         PARTIAL  SIGNIF

                                                 IN
  0    .90344   .82833      11
  1    .90316   .82151      10     4.FEHC       OUT   .05379   .7021
  2    .90299   .81442       9     5.FECO       OUT  -.04134   .7666
  3    .90288   .80729       8     2.FTPCO      OUT   .03329   .8094
  4    .90187   .80408       7    24.RTHP       OUT  -.10160   .4562
  5    .89790   .81283       6    22.VDHP       OUT  -.19718   .1415

<FINISH>
```

Appendix 6

Residual and Ratio Regressions

61. U.D. Jose is the urban fuel economy "delta-residual" using the Bascunana equation.

62. U.D. Dill is the urban fuel economy "delta-residual" using the Murrell equation.

63. U.D. J.P. is the urban fuel economy "delta-residual" using the Cheng equation.

64. U.R. Jose is the urban fuel economy "ratio-residual" using the Bascunana equation.

65. U.R. Dill is the urban fuel economy "ratio-residual" using the Murrell equation.

66. U.R. J.P. is the urban fuel economy "ratio-residual" using the Cheng equation.

When U is replaced by H, urban fuel economy becomes highway fuel economy.

When U is replaced by C, urban fuel economy becomes composite fuel economy.

```
<REGRESS VAR=61-66,71-76,81-86;1>

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 61.UD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  8.8443     8.8443     2.3135     .1295
     ERROR              263  1005.4     3.8230
     TOTAL              264  1014.3

     MULT R= .09338  R-SQR= .00872 SE= 1.9552

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .63058     .33410     1.8874     .0602
   1.FTPHC        -.09338   -2.2958     1.5094     -1.5210     .1295

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 62.UD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .55990     .55990     .17837     .6731
     ERROR              263  825.55     3.1390
     TOTAL              264  826.11

     MULT R= .02603  R-SQR= .00068 SE= 1.7717

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .21263     .30274     .70235     .4831
   1.FTPHC        -.02603   -.57764     1.3677     -.42234     .6731

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 63.UD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .31441     .31441     .91198 -1  .7629
     ERROR              263  906.71     3.4476
     TOTAL              264  907.03

     MULT R= .01862  R-SQR= .00035 SE= 1.8568

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .16228     .31728     .51147     .6095
   1.FTPHC        -.01862   -.43287     1.4334     -.30199     .7629
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 64.UR.JOSE  N= 265 OUT OF 571
     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .16764 -1  .16764 -1  2.2956     .1309
     ERROR              263  1.9207     .73029 -2
     TOTAL              264  1.9374

     MULT R= .09302  R-SQR= .00865 SE= .85457 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT                1.0262     .14603 -1  70.279    0.
   1.FTPHC       -.09302  -.99954 -1  .65971 -1 -1.5151     .1309

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 65.UR.DILL  N= 265 OUT OF 571
     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .43762 -3  .43762 -3  .68481 -1  .7938
     ERROR              263  1.6806     .63903 -2
     TOTAL              264  1.6811

     MULT R= .01613  R-SQR= .00026 SE= .79939 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT                1.0078     .13660 -1  73.779    0.
   1.FTPHC       -.01613  -.16149 -1  .61711 -1 -.26169     .7938

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 66.UR.J.P.  N= 265 OUT OF 571
     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .53910 -3  .53910 -3  .77083 -1  .7815
     ERROR              263  1.8394     .69938 -2
     TOTAL              264  1.8399

     MULT R= .01712  R-SQR= .00029 SE= .83629 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT                1.0077     .14290 -1  70.518    0.
   1.FTPHC       -.01712  -.17924 -1  .64559 -1 -.27764     .7815
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 71.HD.JOSE  N= 265 OUT OF 571

     SOURCE              DF   SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1   6.4400      6.4400      .76549      .3824
     ERROR              263   2212.6      8.4130
     TOTAL              264   2219.1

     MULT R= .05387  R-SQR= .00290 SE= 2.9005

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                -.16283     .49563     -.32854      .7428
   1.FTPHC         .05387    1.9591     2.2391       .87492      .3824

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 72.HD.DILL  N= 265 OUT OF 571

     SOURCE              DF   SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1   15.056      15.056      1.9509      .1637
     ERROR              263   2029.8      7.7177
     TOTAL              264   2044.8

     MULT R= .08581  R-SQR= .00736 SE= 2.7781

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                -.61347     .47471     -1.2923      .1974
   1.FTPHC         .08581    2.9955     2.1446       1.3967      .1637

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 73.HD.J.P.  N= 265 OUT OF 571

     SOURCE              DF   SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1   12.890      12.890      1.5237      .2182
     ERROR              263   2224.9      8.4595
     TOTAL              264   2237.7

     MULT R= .07590  R-SQR= .00576 SE= 2.9085

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                -.52557     .49700     -1.0575      .2913
   1.FTPHC         .07590    2.7716     2.2453       1.2344      .2182
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 74.HR.JOSE  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION            1  .47380 -2   .47380 -2  .57969       .4471
     ERROR               263  2.1496      .81734 -2
     TOTAL               264  2.1543

     MULT R= .04690  R-SQR= .00220 SE= .90407 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .99616     .15448 -1  64.483     0.
   1.FTPHC         .04690    .53138 -1  .69792 -1  .76137      .4471

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 75.HR.DILL  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION            1  .12233 -1   .12233 -1  1.5624       .2124
     ERROR               263  2.0592      .78297 -2
     TOTAL               264  2.0715

     MULT R= .07685  R-SQR= .00591 SE= .88486 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .98270     .15120 -1  64.993     0.
   1.FTPHC         .07685    .85383 -1  .68309 -1  1.2500      .2124

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 76.HR.J.P.  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION            1  .11410 -1   .11410 -1  1.3160       .2524
     ERROR               263  2.2803      .86703 -2
     TOTAL               264  2.2917

     MULT R= .07056  R-SQR= .00498 SE= .93114 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .98630     .15911 -1  61.988     0.
   1.FTPHC         .07056    .82461 -1  .71882 -1  1.1472      .2524
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 81.CD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .97346      .97346     .22704     .6341
     ERROR              263  1127.6      4.2876
     TOTAL              264  1128.6

     MULT R= .02937  R-SQR= .00086 SE= 2.0707

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .24461     .35383     .69132     .4900
   1.FTPHC        -.02937   -.76166     1.5985    -.47649     .6341

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 82.CD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  1.4807      1.4807     .41217     .5214
     ERROR              263  944.80      3.5924
     TOTAL              264  946.28

     MULT R= .03956  R-SQR= .00156 SE= 1.8954

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.18803     .32387    -.58056     .5620
   1.FTPHC         .03956     .93937     1.4632     .64201     .5214

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 83.CD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  1.0476      1.0476     .24816     .6188
     ERROR              263  1110.3      4.2216
     TOTAL              264  1111.3

     MULT R= .03070  R-SQR= .00094 SE= 2.0547

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.15913     .35109    -.45324     .6507
   1.FTPHC         .03070     .79015     1.5861     .49816     .6188
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 84.CR.JOSE  N= 265 OUT OF 571

     SOURCE            DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION         1  .17618 -2   .17618 -2   .28235     .5956
     ERROR            263  1.6411      .62397 -2
     TOTAL            264  1.6428

     MULT R= .03275  R-SQR= .00107 SE= .78992 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT    SIGNIF

     CONSTANT                1.0099     .13498 -1  74.816    0.
   1.FTPHC       -.03275  -.32403 -1  .60980 -1 -.53137     .5956

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 85.CR.DILL  N= 265 OUT OF 571

     SOURCE            DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION         1  .27560 -2   .27560 -2   .48586     .4864
     ERROR            263  1.4919      .56725 -2
     TOTAL            264  1.4946

     MULT R= .04294  R-SQR= .00184 SE= .75316 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT    SIGNIF

     CONSTANT                .99302     .12870 -1  77.160    0.
   1.FTPHC        .04294   .40527 -1  .58142 -1  .69703     .4864

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 86.CR.J.P.  N= 265 OUT OF 571

     SOURCE            DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION         1  .14246 -2   .14246 -2   .22573     .6351
     ERROR            263  1.6598      .63112 -2
     TOTAL            264  1.6613

     MULT R= .02928  R-SQR= .00086 SE= .79443 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT    SIGNIF

     CONSTANT                .99579     .13575 -1  73.355    0.
   1.FTPHC        .02928   .29137 -1  .61328 -1  .47511     .6351
```

```
<REGRESS VAR=61-66,71-76,81-86;2>

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 61.UD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  33.425     33.425     8.9623     .0030
     ERROR              263  980.86     3.7295
     TOTAL              264  1014.3

     MULT R= .18153  R-SQR= .03295 SE= 1.9312

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .79283     .24345     3.2566      .0013
   2.FTPCO       -.18153   -.29846     .99697 -1 -2.9937      .0030

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 62.UD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  18.097     18.097     5.8904     .0159
     ERROR              263  808.02     3.0723
     TOTAL              264  826.11

     MULT R= .14801  R-SQR= .02191 SE= 1.7528

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .56163     .22097     2.5417      .0116
   2.FTPCO       -.14801   -.21961     .90487 -1 -2.4270      .0159

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 63.UD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  20.022     20.022     5.9366     .0155
     ERROR              263  887.00     3.3726
     TOTAL              264  907.03

     MULT R= .14857  R-SQR= .02207 SE= 1.8365

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .56545     .23151     2.4424      .0152
   2.FTPCO       -.14857   -.23100     .94807 -1 -2.4365      .0155
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 64.UR.JOSE  N= 265 OUT OF 571

    SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

    REGRESSION          1  .37122 -1  .37122 -1  5.1377      .0242
    ERROR             263  1.9003     .72255 -2
    TOTAL             264  1.9374

    MULT R= .13842  R-SQR= .01916 SE= .85003 -1

    VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

    CONSTANT                1.0268     .10716 -1  95.822     0.
  2.FTPCO       -.13842   -.99466 -2  .43882 -2 -2.2666      .0242

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 65.UR.DILL  N= 265 OUT OF 571

    SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

    REGRESSION          1  .18843 -1  .18843 -1  2.9814      .0854
    ERROR             263  1.6622     .63203 -2
    TOTAL             264  1.6811

    MULT R= .10587  R-SQR= .01121 SE= .79500 -1

    VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

    CONSTANT                1.0196     .10022 -1  101.73     0.
  2.FTPCO       -.10587   -.70865 -2  .41042 -2 -1.7267      .0854

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 66.UR.J.P.  N= 265 OUT OF 571

    SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

    REGRESSION          1  .25773 -1  .25773 -1  3.7364      .0543
    ERROR             263  1.8141     .68978 -2
    TOTAL             264  1.8399

    MULT R= .11835  R-SQR= .01401 SE= .83053 -1

    VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

    CONSTANT                1.0217     .10470 -1  97.582     0.
  2.FTPCO       -.11835   -.82878 -2  .42876 -2 -1.9330      .0543
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 71.HD.JOSE   N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1  14.171      14.171      1.6903      .1947
     ERROR              263  2204.9      8.3836
     TOTAL              264  2219.1

     MULT R= .07991  R-SQR= .00639 SE= 2.8954

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                 .65622      .36501     1.7978      .0734
   2.FTPCO        -.07991   -.19434      .14948    -1.3001      .1947

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 72.HD.DILL   N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1  3.9110      3.9110      .50399      .4784
     ERROR              263  2040.9      7.7601
     TOTAL              264  2044.8

     MULT R= .04373  R-SQR= .00191 SE= 2.7857

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                 .22295      .35118     .63487      .5261
   2.FTPCO        -.04373   -.10209      .14381    -.70992      .4784

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 73.HD.J.P.   N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1  26.006      26.006      3.0924      .0798
     ERROR              263  2211.7      8.4097
     TOTAL              264  2237.7

     MULT R= .10780  R-SQR= .01162 SE= 2.8999

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                 .60830      .36558     1.6639      .0973
   2.FTPCO        -.10780   -.26327      .14971    -1.7585      .0798
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 74.HR.JOSE  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION            1  .75769 -2  .75769 -2  .92825     .3362
     ERROR               263  2.1468     .81626 -2
     TOTAL               264  2.1543

     MULT R= .05930  R-SQR= .00352 SE= .90347 -1

     VARIABLE     PARTIAL    COEFF      STD ERROR  T-STAT    SIGNIF

     CONSTANT               1.0167     .11390 -1  89.267    O.
   2.FTPCO        -.05930  -.44937 -2  .46641 -2 -.96346     .3362

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 75.HR.DILL  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION            1  .14062 -2  .14062 -2  .17866     .6729
     ERROR               263  2.0700     .78709 -2
     TOTAL               264  2.0715

     MULT R= .02605  R-SQR= .00068 SE= .88718 -1

     VARIABLE     PARTIAL    COEFF      STD ERROR  T-STAT    SIGNIF

     CONSTANT               1.0045     .11184 -1  89.811    O.
   2.FTPCO        -.02605  -.19359 -2  .45800 -2 -.42268     .6729

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 76.HR.J.P.  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION            1  .19343 -1  .19343 -1  2.2387     .1358
     ERROR               263  2.2724     .86401 -2
     TOTAL               264  2.2917

     MULT R= .09187  R-SQR= .00844 SE= .92952 -1

     VARIABLE     PARTIAL    COEFF      STD ERROR  T-STAT    SIGNIF

     CONSTANT               1.0186     .11718 -1  86.929    O.
   2.FTPCO        -.09187  -.71799 -2  .47986 -2 -1.4962     .1358
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 81.CD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  24.568     24.568     5.8523     .0162
     ERROR              263  1104.1     4.1979
     TOTAL              264  1128.6

     MULT R= .14754  R-SQR= .02177 SE= 2.0489

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .63293     .25829     2.4504     .0149
   2.FTPCO       -.14754  -.25588      .10577    -2.4192     .0162

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 82.CD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  9.6420     9.6420     2.7074     .1011
     ERROR              263  936.64     3.5614
     TOTAL              264  946.28

     MULT R= .10094  R-SQR= .01019 SE= 1.8872

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .34783     .23790     1.4621     .1449
   2.FTPCO       -.10094  -.16030      .97424 -1 -1.6454     .1011

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 83.CD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  19.922     19.922     4.8007     .0293
     ERROR              263  1091.4     4.1498
     TOTAL              264  1111.3

     MULT R= .13389  R-SQR= .01793 SE= 2.0371

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .49543     .25681     1.9292     .0548
   2.FTPCO       -.13389  -.23042      .10517    -2.1910     .0293
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VAR[illegible]E OF 84.CR.JOSE  N= 265 OUT OF 571
    SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

    REGRESSION            1  .19776 -1  .19776 -1  3.2045     .0746
    ERROR               263  1.6230     .61713 -2
    TOTAL               264  1.6428

    MULT R= .10972  R-SQR= .01204 SE= .78557 -1

    VARIABLE     PARTIAL     COEFF     STD ERROR  T-STAT    SIGNIF

    CONSTANT                1.0186     .99033 -2  102.86    O.
  2.FTPCO        -.10972  -.72597 -2  .40555 -2 -1.7901      .0746
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 85.CR.DILL  N= 265 OUT OF 571
    SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

    REGRESSION            1  .62646 -2  .62646 -2  1.1070     .2937
    ERROR               263  1.4883     .56591 -2
    TOTAL               264  1.4946

    MULT R= .06474  R-SQR= .00419 SE= .75227 -1

    VARIABLE     PARTIAL     COEFF     STD ERROR  T-STAT    SIGNIF

    CONSTANT                1.0101     .94835 -2  106.51    O.
  2.FTPCO        -.06474  -.40860 -2  .38836 -2 -1.0521      .2937
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 86.CR.J.P.  N= 265 OUT OF 571
    SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

    REGRESSION            1  .19604 -1  .19604 -1  3.1407     .0775
    ERROR               263  1.6417     .62421 -2
    TOTAL               264  1.6613

    MULT R= .10863  R-SQR= .01180 SE= .79007 -1

    VARIABLE     PARTIAL     COEFF     STD ERROR  T-STAT    SIGNIF

    CONSTANT                1.0172     .99599 -2  102.13    O.
  2.FTPCO        -.10863  -.72282 -2  .40787 -2 -1.7722      .0775
```

```
<REGRESS VAR=61-66,71-76,81-86;3>

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 61.UD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  34.716      34.716     9.3206     .0025
     ERROR              263  979.57      3.7246
     TOTAL              264  1014.3

     MULT R= .18500  R-SQR= .03423 SE= 1.9299

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.62211     .28121    -2.2123     .0278
   3.FTPNOX        .18500    1.4213      .46554     3.0530     .0025

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 62.UD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  10.159      10.159     3.2744     .0715
     ERROR              263  815.95      3.1025
     TOTAL              264  826.11

     MULT R= .11089  R-SQR= .01230 SE= 1.7614

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.32780     .25665    -1.2772     .2026
   3.FTPNOX        .11089     .76884     .42489     1.8095     .0715

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 63.UD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  20.186      20.186     5.9862     .0151
     ERROR              263  886.84      3.3720
     TOTAL              264  907.03

     MULT R= .14918  R-SQR= .02225 SE= 1.8363

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.52076     .26757    -1.9463     .0527
   3.FTPNOX        .14918    1.0838      .44296     2.4467     .0151
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 64.UR.JOSE  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  .74805 -1  .74805 -1  10.562     .0013
     ERROR             263  1.8626     .70822 -2
     TOTAL             264  1.9374

     MULT R= .19650  R-SQR= .03861 SE= .84156 -1

     VARIABLE    PARTIAL    COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT               .96947     .12262 -1  79.061    O.
   3.FTPNOX       .19650    .65976 -1  .20300 -1  3.2500     .0013

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 65.UR.DILL  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  .17617 -1  .17617 -1  2.7853     .0963
     ERROR             263  1.6635     .63250 -2
     TOTAL             264  1.6811

     MULT R= .10237  R-SQR= .01048 SE= .79530 -1

     VARIABLE    PARTIAL    COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT               .98693     .11588 -1  85.167    O.
   3.FTPNOX       .10237    .32017 -1  .19184 -1  1.6689     .0963

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 66.UR.J.P.  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  .41685 -1  .41685 -1  6.0967     .0142
     ERROR             263  1.7982     .68373 -2
     TOTAL             264  1.8399

     MULT R= .15052  R-SQR= .02266 SE= .82688 -1

     VARIABLE    PARTIAL    COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT               .97704     .12048 -1  81.093    O.
   3.FTPNOX       .15052    .49250 -1  .19946 -1  2.4692     .0142
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 71.HD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  53.998      53.998     6.5594     .0110
     ERROR              263  2165.1      8.2322
     TOTAL              264  2219.1

     MULT R= .15599  R-SQR= .02433 SE= 2.8692

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.72910     .41806    -1.7440     .0823
   3.FTPNOX        .15599    1.7726      .69211     2.5611     .0110

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 72.HD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  25.480      25.480     3.3185     .0696
     ERROR              263  2019.3      7.6781
     TOTAL              264  2044.8

     MULT R= .11163  R-SQR= .01246 SE= 2.7709

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.66170     .40375    -1.6389     .1024
   3.FTPNOX        .11163    1.2176      .66841     1.8217     .0696

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 73.HD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  30.767      30.767     3.6665     .0566
     ERROR              263  2207.0      8.3916
     TOTAL              264  2237.7

     MULT R= .11726  R-SQR= .01375 SE= 2.8968

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                -.68598     .42209    -1.6252     .1053
   3.FTPNOX        .11726    1.3380      .69878     1.9148     .0566
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 74.HR.JOSE  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION            1  .58894 -1   .58894 -1  7.3918      .0070
     ERROR               263  2.0954      .79674 -2
     TOTAL               264  2.1543

     MULT R= .16534  R-SQR= .02734 SE= .89261 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .97507      .13006 -1  74.970    0.
   3.FTPNOX        .16534    .58540 -1   .21532 -1  2.7188     .0070

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 75.HR.DILL  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION            1  .21948 -1   .21948 -1  2.8165      .0945
     ERROR               263  2.0495      .77928 -2
     TOTAL               264  2.0715

     MULT R= .10294  R-SQR= .01060 SE= .88277 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .98076      .12863 -1  76.248    0.
   3.FTPNOX        .10294    .35737 -1   .21294 -1  1.6782     .0945

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 76.HR.J.P.  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION            1  .28946 -1   .28946 -1  3.3644      .0678
     ERROR               263  2.2628      .86036 -2
     TOTAL               264  2.2917

     MULT R= .11239  R-SQR= .01263 SE= .92756 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .98085      .13515 -1  72.573    0.
   3.FTPNOX        .11239    .41040 -1   .22375 -1  1.8342     .0678
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 81.CD.JOSE  N= 265 OUT OF 571

     SOURCE            DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION         1  42.470     42.470     10.284     .0015
     ERROR            263  1086.1     4.1298
     TOTAL            264  1128.6

     MULT R= .19399  R-SQR= .03763 SE= 2.0322

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.77378      .29611    -2.6131     .0095
   3.FTPNOX         .19399   1.5720      .49022     3.2068     .0015

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 82.CD.DILL  N= 265 OUT OF 571

     SOURCE            DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION         1  10.797     10.797     3.0354     .0826
     ERROR            263  935.48     3.5570
     TOTAL            264  946.28

     MULT R= .10682  R-SQR= .01141 SE= 1.8860

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.42815      .27481    -1.5580     .1204
   3.FTPNOX         .10682   .79262      .45495     1.7422     .0826

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 83.CD.J.P.  N= 265 OUT OF 571

     SOURCE            DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION         1  16.489     16.489     3.9610     .0476
     ERROR            263  1094.8     4.1629
     TOTAL            264  1111.3

     MULT R= .12181  R-SQR= .01484 SE= 2.0403

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.53245      .29729    -1.7910     .0744
   3.FTPNOX         .12181   .97954      .49217     1.9902     .0476
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 84.CR.JOSE  N= 265 OUT OF 571
     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION            1  .69217 -1   .69217 -1   11.568     .0008
     ERROR               263  1.5736      .59833 -2
     TOTAL               264  1.6428

     MULT R= .20526  R-SQR= .04213 SE= .77352 -1

     VARIABLE     PARTIAL    COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT               .96840      .11271 -1   85.921    0.
   3.FTPNOX       .20526    .63464 -1   .18659 -1   3.4012     .0008

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 85.CR.DILL  N= 265 OUT OF 571
     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION            1  .12375 -1   .12375 -1   2.1958     .1396
     ERROR               263  1.4822      .56359 -2
     TOTAL               264  1.4946

     MULT R= .09099  R-SQR= .00828 SE= .75073 -1

     VARIABLE     PARTIAL    COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT               .98669      .10939 -1   90.202    0.
   3.FTPNOX       .09099    .26835 -1   .18109 -1   1.4818     .1396

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 86.CR.J.P.  N= 265 OUT OF 571
     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION            1  .21965 -1   .21965 -1   3.5239     .0616
     ERROR               263  1.6393      .62331 -2
     TOTAL               264  1.6613

     MULT R= .11499  R-SQR= .01322 SE= .78950 -1

     VARIABLE     PARTIAL    COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT               .98222      .11504 -1   85.383    0.
   3.FTPNOX       .11499    .35751 -1   .19045 -1   1.8772     .0616
```

```
<REGRESS VAR=61-66,71-76,81-86;4>

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 61.UD.JOSE  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION            1  16.233      16.233      4.2776      .0396
     ERROR               263  998.05      3.7949
     TOTAL               264  1014.3

     MULT R= .12651  R-SQR= .01600 SE= 1.9480

     VARIABLE     PARTIAL      COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                  .43330     .17958     2.4129      .0165
   4.FEHC        -.12651    -6.1138      2.9561     -2.0682      .0396

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 62.UD.DILL  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION            1  4.0773      4.0773      1.3045      .2544
     ERROR               263  822.03      3.1256
     TOTAL               264  826.11

     MULT R= .07025  R-SQR= .00494 SE= 1.7679

     VARIABLE     PARTIAL      COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                  .23211     .16297     1.4242      .1556
   4.FEHC        -.07025    -3.0641      2.6828     -1.1421      .2544

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 63.UD.J.P.  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION            1  8.7314      8.7314      2.5563      .1111
     ERROR               263  898.29      3.4156
     TOTAL               264  907.03

     MULT R= .09811  R-SQR= .00963 SE= 1.8481

     VARIABLE     PARTIAL      COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                  .27596     .17037     1.6198      .1065
   4.FEHC        -.09811    -4.4839      2.8045     -1.5989      .1111
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 64.UR.JOSE  N= 265 OUT OF 571

     SOURCE              DF   SUM SQRS     MEAN SQR     F-STAT     SIGNIF

     REGRESSION           1   .27433 -1    .27433 -1    3.7774      .0530
     ERROR              263   1.9100       .72623 -2
     TOTAL              264   1.9374

     MULT R= .11899  R-SQR= .01416 SE= .85219 -1

     VARIABLE     PARTIAL     COEFF      STD ERROR    T-STAT     SIGNIF

     CONSTANT                 1.0170      .78558 -2   129.46     0.
   4.FEHC        -.11899    -.25134       .12932     -1.9436      .0530

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 65.UR.DILL  N= 265 OUT OF 571

     SOURCE              DF   SUM SQRS     MEAN SQR     F-STAT     SIGNIF

     REGRESSION           1   .31472 -2    .31472 -2    .49329      .4831
     ERROR              263   1.6779       .63800 -2
     TOTAL              264   1.6811

     MULT R= .04327  R-SQR= .00187 SE= .79875 -1

     VARIABLE     PARTIAL     COEFF      STD ERROR    T-STAT     SIGNIF

     CONSTANT                 1.0083      .73631 -2   136.94     0.
   4.FEHC        -.04327    -.85130 -1    .12121     -.70235      .4831

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 66.UR.J.P.  N= 265 OUT OF 571

     SOURCE              DF   SUM SQRS     MEAN SQR     F-STAT     SIGNIF

     REGRESSION           1   .97938 -2    .97938 -2    1.4074      .2366
     ERROR              263   1.8301       .69586 -2
     TOTAL              264   1.8399

     MULT R= .07296  R-SQR= .00532 SE= .83418 -1

     VARIABLE     PARTIAL     COEFF      STD ERROR    T-STAT     SIGNIF

     CONSTANT                 1.0108      .76898 -2   131.45     0.
   4.FEHC        -.07296    -.15017       .12658     -1.1864      .2366
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 71.HD.JOSE  N= 265 OUT OF 571
   SOURCE               DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

   REGRESSION            1   12.415     12.415    1.4797      .2249
   ERROR               263   2206.6     8.3903
   TOTAL               264   2219.1

   MULT R= .07480  R-SQR= .00559 SE= 2.8966

   VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

   CONSTANT                  .48399     .26702     1.8126     .0710
 4.FEHC         -.07480   -5.3468     4.3955    -1.2164     .2249
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 72.HD.DILL  N= 265 OUT OF 571
   SOURCE               DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

   REGRESSION            1   6.7280     6.7280     .86819     .3523
   ERROR               263   2038.1     7.7494
   TOTAL               264   2044.8

   MULT R= .05736  R-SQR= .00329 SE= 2.7838

   VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

   CONSTANT                  .18353     .25662     .71517     .4751
 4.FEHC         -.05736   -3.9360     4.2243    -.93177     .3523
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 73.HD.J.P.  N= 265 OUT OF 571
   SOURCE               DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

   REGRESSION            1   7.4205     7.4205     .87503     .3504
   ERROR               263   2230.3     8.4803
   TOTAL               264   2237.7

   MULT R= .05759  R-SQR= .00332 SE= 2.9121

   VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

   CONSTANT                  .23414     .26845     .87219     .3839
 4.FEHC         -.05759   -4.1337     4.4190    -.93543     .3504
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 74.HR.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .11086 -1   .11086 -1  1.3604      .2445
     ERROR              263  2.1432      .81492 -2
     TOTAL              264  2.1543

     MULT R= .07173  R-SQR= .00515 SE= .90273 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                1.0144      .83217 -2  121.89     0.
   4.FEHC         -.07173  -.15977      .13699     -1.1663     .2445

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 75.HR.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .55034 -2   .55034 -2  .70059      .4033
     ERROR              263  2.0659      .78553 -2
     TOTAL              264  2.0715

     MULT R= .05154  R-SQR= .00266 SE= .88630 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                1.0054      .81702 -2  123.06     0.
   4.FEHC         -.05154  -.11257      .13449     -.83701     .4033

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 76.HR.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  .42297 -2   .42297 -2  .48631      .4862
     ERROR              263  2.2875      .86976 -2
     TOTAL              264  2.2917

     MULT R= .04296  R-SQR= .00185 SE= .93261 -1

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                1.0078      .85971 -2  117.23     0.
   4.FEHC         -.04296  -.98690 -1  .14152     -.69736     .4862
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 81.CD.JOSE  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  13.009      13.009     3.0669     .0811
     ERROR             263  1115.6      4.2419
     TOTAL             264  1128.6

     MULT R= .10736  R-SQR= .01153 SE= 2.0596

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .33519     .18986     1.7655     .0786
   4.FEHC        -.10736   -5.4733     3.1253     -1.7513     .0811

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 82.CD.DILL  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  3.0180      3.0180     .84147     .3598
     ERROR             263  943.26      3.5866
     TOTAL             264  946.28

     MULT R= .05647  R-SQR= .00319 SE= 1.8938

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .12540     .17458     .71833     .4732
   4.FEHC        -.05647   -2.6362     2.8738     -.91732     .3598

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 83.CD.J.P.  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  5.2814      5.2814     1.2558     .2635
     ERROR             263  1106.0      4.2055
     TOTAL             264  1111.3

     MULT R= .06894  R-SQR= .00475 SE= 2.0507

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                .16203     .18904     .85712     .3922
   4.FEHC        -.06894   -3.4873     3.1119     -1.1206     .2635
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 84.CR.JOSE   N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION          1  .16863 -1   .16863 -1   2.7277       .0998
     ERROR             263  1.6260      .61823 -2
     TOTAL             264  1.6428

     MULT R= .10132  R-SQR= .01026 SE= .78628 -1

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                 1.0121      .72482 -2  139.63     O.
   4.FEHC         -.10132   -.19706      .11931     -1.6516      .0998

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 85.CR.DILL   N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION          1  .15659 -2   .15659 -2   .27583       .5999
     ERROR             263  1.4930      .56770 -2
     TOTAL             264  1.4946

     MULT R= .03237  R-SQR= .00105 SE= .75346 -1

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                 1.0041      .69456 -2  144.57     O.
   4.FEHC         -.03237   -.60048 -1  .11433     -.52520      .5999

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 86.CR.J.P.   N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION          1  .23426 -2   .23426 -2   .37139       .5428
     ERROR             263  1.6589      .63077 -2
     TOTAL             264  1.6613

     MULT R= .03755  R-SQR= .00141 SE= .79421 -1

     VARIABLE      PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                 1.0051      .73213 -2  137.29     O.
   4.FEHC         -.03755   -.73446 -1  .12052     -.60942      .5428
```

```
<REGRESS VAR=61-66,71-76,81-86;5>

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 61.UD.JOSE   N= 265 OUT OF 571

        SOURCE               DF   SUM SQRS    MEAN SQR    F-STAT     SIGNIF

        REGRESSION            1   25.244      25.244      6.7129      .0101
        ERROR               263   989.04      3.7606
        TOTAL               264   1014.3

        MULT R= .15776  R-SQR= .02489 SE= 1.9392

        VARIABLE      PARTIAL      COEFF      STD ERROR    T-STAT     SIGNIF

        CONSTANT                   .31744      .13437      2.3624     .0189
      5.FECO         -.15776    -.34475      .13306     -2.5909     .0101

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 62.UD.DILL   N= 265 OUT OF 571

        SOURCE               DF   SUM SQRS    MEAN SQR    F-STAT     SIGNIF

        REGRESSION            1   10.485      10.485      3.3809      .0671
        ERROR               263   815.63      3.1012
        TOTAL               264   826.11

        MULT R= .11266  R-SQR= .01269 SE= 1.7610

        VARIABLE      PARTIAL      COEFF      STD ERROR    T-STAT     SIGNIF

        CONSTANT                   .19712      .12202      1.6154     .1074
      5.FECO         -.11266    -.22218      .12084     -1.8387     .0671

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 63.UD.J.P.   N= 265 OUT OF 571

        SOURCE               DF   SUM SQRS    MEAN SQR    F-STAT     SIGNIF

        REGRESSION            1   16.608      16.608      4.9056      .0276
        ERROR               263   890.42      3.3856
        TOTAL               264   907.03

        MULT R= .13532  R-SQR= .01831 SE= 1.8400

        VARIABLE      PARTIAL      COEFF      STD ERROR    T-STAT     SIGNIF

        CONSTANT                   .20350      .12749      1.5962     .1116
      5.FECO         -.13532    -.27963      .12625     -2.2149     .0276
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 64.UR.JOSE  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION          1  .44267 -1   .44267 -1  6.1497      .0138
     ERROR             263  1.8932      .71983 -2
     TOTAL             264  1.9374

     MULT R= .15116  R-SQR= .02285 SE= .84843 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                1.0123     .58788 -2  172.20     O.
   5.FECO        -.15116  -.14437 -1   .58216 -2 -2.4799      .0138

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 65.UR.DILL  N= 265 OUT OF 571

     SOURCE             DF  SUM,SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION          1  .16692 -1   .16692 -1  2.6377      .1056
     ERROR             263  1.6644      .63285 -2
     TOTAL             264  1.6811

     MULT R= .09965  R-SQR= .00993 SE= .79552 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                1.0086     .55122 -2  182.98     O.
   5.FECO        -.09965  -.88652 -2   .54586 -2 -1.6241      .1056

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 66.UR.J.P.  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION          1  .30796 -1   .30796 -1  4.4770      .0353
     ERROR             263  1.8091      .68787 -2
     TOTAL             264  1.8399

     MULT R= .12937  R-SQR= .01674 SE= .82938 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT                1.0096     .57468 -2  175.69     O.
   5.FECO        -.12937  -.12041 -1   .56909 -2 -2.1159      .0353
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 71.HD.JOSE  N= 265 OUT OF 571

     SOURCE                DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION             1  43.878      43.878      5.3053      .0220
     ERROR                263  2175.2      8.2706
     TOTAL                264  2219.1

     MULT R= .14062  R-SQR= .01977 SE= 2.8759

     VARIABLE      PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                  .45415     .19927      2.2791      .0235
   5.FECO          -.14062   -.45452     .19733     -2.3033      .0220

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 72.HD.DILL  N= 265 OUT OF 571

     SOURCE                DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION             1  23.446      23.446      3.0506      .0819
     ERROR                263  2021.4      7.6858
     TOTAL                264  2044.8

     MULT R= .10708  R-SQR= .01147 SE= 2.7723

     VARIABLE      PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                  .16046     .19210      .83532      .4043
   5.FECO          -.10708   -.33225     .19023     -1.7466      .0819

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 73.HD.J.P.  N= 265 OUT OF 571

     SOURCE                DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION             1  20.647      20.647      2.4492      .1188
     ERROR                263  2217.1      8.4300
     TOTAL                264  2237.7

     MULT R= .09605  R-SQR= .00923 SE= 2.9035

     VARIABLE      PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                  .19256     .20118      .95715      .3394
   5.FECO          -.09605   -.31178     .19922     -1.5650      .1188
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 74.HR.JOSE  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  .36739 -1  .36739 -1  4.5629     .0336
     ERROR             263  2.1176     .80517 -2
     TOTAL             264  2.1543

     MULT R= .13059  R-SQR= .01705 SE= .89731 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT                1.0133     .62175 -2  162.97    0.
   5.FECO        -.13059  -.13152 -1   .61570 -2 -2.1361     .0336

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 75.HR.DILL  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  .18341 -1  .18341 -1  2.3494     .1265
     ERROR             263  2.0531     .78065 -2
     TOTAL             264  2.0715

     MULT R= .09410  R-SQR= .00885 SE= .88354 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT                1.0047     .61221 -2  164.11    0.
   5.FECO        -.09410  -.92926 -2   .60626 -2 -1.5328     .1265

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 76.HR.J.P.  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION          1  .11194 -1  .11194 -1  1.2910     .2569
     ERROR             263  2.2805     .86711 -2
     TOTAL             264  2.2917

     MULT R= .06989  R-SQR= .00488 SE= .93119 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR  T-STAT    SIGNIF

     CONSTANT                1.0067     .64522 -2  156.03    0.
   5.FECO        -.06989  -.72599 -2   .63895 -2 -1.1362     .2569
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 81.CD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1  28.200      28.200      6.7398      .0100
     ERROR              263  1100.4      4.1841
     TOTAL              264  1128.6

     MULT R= .15807  R-SQR= .02499 SE= 2.0455

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                 .25751     .14173      1.8168      .0704
   5.FECO         -.15807   -.36438     .14036     -2.5961      .0100

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 82.CD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1  10.559      10.559      2.9677      .0861
     ERROR              263  935.72      3.5579
     TOTAL              264  946.28

     MULT R= .10563  R-SQR= .01116 SE= 1.8862

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                 .11016     .13070      .84287      .4001
   5.FECO         -.10563   -.22296     .12943     -1.7227      .0861

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 83.CD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT     SIGNIF

     REGRESSION           1  13.310      13.310      3.1880      .0753
     ERROR              263  1098.0      4.1750
     TOTAL              264  1111.3

     MULT R= .10944  R-SQR= .01198 SE= 2.0433

     VARIABLE     PARTIAL     COEFF     STD ERROR    T-STAT     SIGNIF

     CONSTANT                 .12102     .14158      .85480      .3934
   5.FECO         -.10944   -.25033     .14020     -1.7855      .0753
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 84.CR.JOSE  N= 265 OUT OF 571

        SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT     SIGNIF

        REGRESSION           1  .36751 -1  .36751 -1  6.0182       .0148
        ERROR              263  1.6061     .61067 -2
        TOTAL              264  1.6428

        MULT R= .14957  R-SQR= .02237 SE= .78145 -1

        VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

        CONSTANT                1.0093     .54147 -2  186.40     0.
      5.FECO        -.14957  -.13154 -1  .53620 -2 -2.4532      .0148

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 85.CR.DILL  N= 265 OUT OF 571

        SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT     SIGNIF

        REGRESSION           1  .11913 -1  .11913 -1  2.1131       .1472
        ERROR              263  1.4827     .56376 -2
        TOTAL              264  1.4946

        MULT R= .08928  R-SQR= .00797 SE= .75084 -1

        VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

        CONSTANT                1.0049     .52026 -2  193.15     0.
      5.FECO        -.08928  -.74891 -2  .51520 -2 -1.4536      .1472

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 86.CR.J.P.  N= 265 OUT OF 571

        SOURCE              DF  SUM SQRS    MEAN SQR   F-STAT     SIGNIF

        REGRESSION           1  .13848 -1  .13848 -1  2.2107       .1383
        ERROR              263  1.6474     .62639 -2
        TOTAL              264  1.6613

        MULT R= .09130  R-SQR= .00834 SE= .79145 -1

        VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

        CONSTANT                1.0056     .54840 -2  183.37     0.
      5.FECO        -.09130  -.80745 -2  .54306 -2 -1.4868      .1383
```

```
<REGRESS VAR=61-66,71-76,81-86;6>

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 61.UD.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  21.292     21.292     5.6394     .0183
     ERROR              263  992.99     3.7756
     TOTAL              264  1014.3

     MULT R= .14489  R-SQR= .02099 SE= 1.9431

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.19055     .18865    -1.0100    .3134
   6.FENOX         .14489    .77445     .32612     2.3747    .0183

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 62.UD.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  4.4607     4.4607     1.4278     .2332
     ERROR              263  821.65     3.1242
     TOTAL              264  826.11

     MULT R= .07348  R-SQR= .00540 SE= 1.7675

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.65472 -1  .17161    -.38152    .7031
   6.FENOX         .07348    .35448     .29666     1.1949    .2332

LEAST SQUARES REGRESSION


ANALYSIS OF VARIANCE OF 63.UD.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION           1  5.6669     5.6669     1.6535     .1996
     ERROR              263  901.36     3.4272
     TOTAL              264  907.03

     MULT R= .07904  R-SQR= .00625 SE= 1.8513

     VARIABLE     PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.10611     .17974    -.59036    .5555
   6.FENOX         .07904    .39954     .31071     1.2859    .1996
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 64.UR.JOSE  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT     SIGNIF

     REGRESSION          1  .28712 -1  .28712 -1  3.9562      .0477
     ERROR             263  1.9087     .72575 -2
     TOTAL             264  1.9374

     MULT R= .12174  R-SQR= .01482 SE= .85191 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .99286     .82711 -2  120.04     0.
   6.FENOX         .12174    .28439 -1  .14298 -1  1.9890      .0477

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 65.UR.DILL  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT     SIGNIF

     REGRESSION          1  .15571 -2  .15571 -2  .24383      .6219
     ERROR             263  1.6795     .63860 -2
     TOTAL             264  1.6811

     MULT R= .03043  R-SQR= .00093 SE= .79913 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                1.0015     .77586 -2  129.08     0.
   6.FENOX         .03043    .66229 -2  .13412 -1  .49379      .6219

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 66.UR.J.P.  N= 265 OUT OF 571

     SOURCE             DF  SUM SQRS   MEAN SQR   F-STAT     SIGNIF

     REGRESSION          1  .36590 -2  .36590 -2  .52407      .4698
     ERROR             263  1.8362     .69819 -2
     TOTAL             264  1.8399

     MULT R= .04459  R-SQR= .00199 SE= .83558 -1

     VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT     SIGNIF

     CONSTANT                .99947     .81126 -2  123.20     0.
   6.FENOX         .04459    .10152 -1  .14024 -1  .72393      .4698
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 71.HD.JOSE  N= 265 OUT OF 571

    SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

    REGRESSION            1  22.388     22.388     2.6805     .1028
    ERROR               263  2196.7     8.3524
    TOTAL               264  2219.1

    MULT R= .10044  R-SQR= .01009 SE= 2.8900

    VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

    CONSTANT                -.11393    .28059     -.40604    .6850
  6.FENOX        .10044      .79414    .48505     1.6372     .1028

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 72.HD.DILL  N= 265 OUT OF 571

    SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

    REGRESSION            1  8.2792     8.2792     1.0692     .3021
    ERROR               263  2036.5     7.7435
    TOTAL               264  2044.8

    MULT R= .06363  R-SQR= .00405 SE= 2.7827

    VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

    CONSTANT                -.21109    .27017     -.78131    .4353
  6.FENOX        .06363      .48293    .46704     1.0340     .3021

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 73.HD.J.P.  N= 265 OUT OF 571

    SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

    REGRESSION            1  17.296     17.296     2.0487     .1535
    ERROR               263  2220.4     8.4428
    TOTAL               264  2237.7

    MULT R= .08792  R-SQR= .00773 SE= 2.9056

    VARIABLE     PARTIAL     COEFF     STD ERROR   T-STAT    SIGNIF

    CONSTANT                -.26578    .28211     -.94212    .3470
  6.FENOX        .08792      .69801    .48767     1.4313     .1535
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 74.HR.JOSE  N= 265 OUT OF 571

     SOURCE                DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION             1  .21243 -1  .21243 -1  2.6192      .1068
     ERROR                263  2.1331     .81106 -2
     TOTAL                264  2.1543

     MULT R= .09930  R-SQR= .00986 SE= .90059 -1

     VARIABLE      PARTIAL     COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .99617      .87437 -2  113.93     0.
   6.FENOX          .09930    .24462 -1  .15115 -1  1.6184      .1068

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 75.HR.DILL  N= 265 OUT OF 571

     SOURCE                DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION             1  .59035 -2  .59035 -2  .75167      .3867
     ERROR                263  2.0655     .78538 -2
     TOTAL                264  2.0715

     MULT R= .05338  R-SQR= .00285 SE= .88622 -1

     VARIABLE      PARTIAL     COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .99456      .86042 -2  115.59     0.
   6.FENOX          .05338    .12896 -1  .14874 -1  .86699      .3867

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 76.HR.J.P.  N= 265 OUT OF 571

     SOURCE                DF  SUM SQRS    MEAN SQR   F-STAT    SIGNIF

     REGRESSION             1  .12505 -1  .12505 -1  1.4430      .2307
     ERROR                263  2.2792     .86661 -2
     TOTAL                264  2.2917

     MULT R= .07387  R-SQR= .00546 SE= .93092 -1

     VARIABLE      PARTIAL     COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT                 .99492      .90382 -2  110.08     0.
   6.FENOX          .07387    .18769 -1  .15624 -1  1.2013      .2307
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 81.CD.JOSE  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION            1  20.133     20.133     4.7768     .0297
     ERROR               263  1108.5     4.2148
     TOTAL               264  1128.6

     MULT R= .13356  R-SQR= .01784 SE= 2.0530

     VARIABLE      PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.25007     .19932    -1.2546     .2107
   6.FENOX         .13356    .75308     .34457     2.1856     .0297

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 82.CD.DILL  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION            1  2.8629     2.8629     .79811     .3725
     ERROR               263  943.42     3.5871
     TOTAL               264  946.28

     MULT R= .05500  R-SQR= .00303 SE= 1.8940

     VARIABLE      PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.12121     .18388    -.65918     .5104
   6.FENOX         .05500    .28398     .31788     .89337     .3725

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 83.CD.J.P.  N= 265 OUT OF 571

     SOURCE               DF  SUM SQRS   MEAN SQR   F-STAT    SIGNIF

     REGRESSION            1  4.2221     4.2221     1.0030     .3175
     ERROR               263  1107.1     4.2095
     TOTAL               264  1111.3

     MULT R= .06164  R-SQR= .00380 SE= 2.0517

     VARIABLE      PARTIAL    COEFF     STD ERROR   T-STAT    SIGNIF

     CONSTANT               -.15041     .19920    -.75508     .4509
   6.FENOX         .06164    .34487     .34435     1.0015     .3175
```

```
LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 84.CR.JOSE  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION           1  .22586 -1   .22586 -1   3.6662     .0566
     ERROR              263  1.6202      .61606 -2
     TOTAL              264  1.6428

     MULT R= .11725  R-SQR= .01375 SE= .78489 -1

     VARIABLE     PARTIAL     COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT                .99186      .76205 -2   130.16    0.
   6.FENOX        .11725     .25223 -1   .13173 -1   1.9147     .0566

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 85.CR.DILL  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT      SIGNIF

     REGRESSION           1  .46362 -3   .46362 -3   .81606 -1   .7754
     ERROR              263  1.4941      .56812 -2
     TOTAL              264  1.4946

     MULT R= .01761  R-SQR= .00031 SE= .75374 -1

     VARIABLE     PARTIAL     COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT                .99977      .73179 -2   136.62    0.
   6.FENOX        .01761     .36138 -2   .12650 -1   .28567     .7754

LEAST SQUARES REGRESSION

ANALYSIS OF VARIANCE OF 86.CR.J.P.  N= 265 OUT OF 571

     SOURCE              DF  SUM SQRS    MEAN SQR    F-STAT    SIGNIF

     REGRESSION           1  .11715 -2   .11715 -2   .18560     .6670
     ERROR              263  1.6601      .63121 -2
     TOTAL              264  1.6613

     MULT R= .02656  R-SQR= .00071 SE= .79449 -1

     VARIABLE     PARTIAL     COEFF      STD ERROR   T-STAT    SIGNIF

     CONSTANT                .99923      .77136 -2   129.54    0.
   6.FENOX        .02656     .57446 -2   .13334 -1   .43081     .6670
```

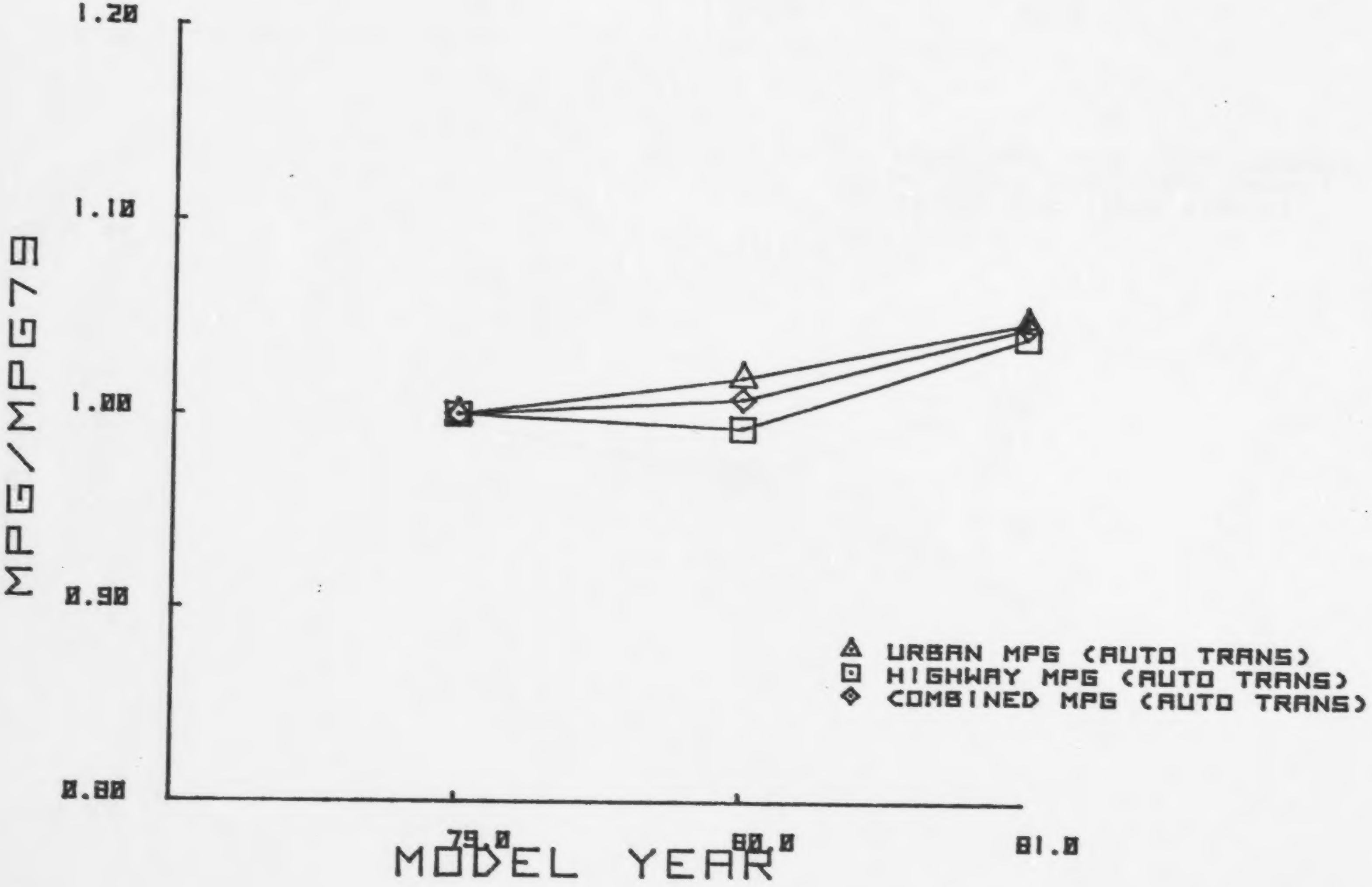
Appendix 7

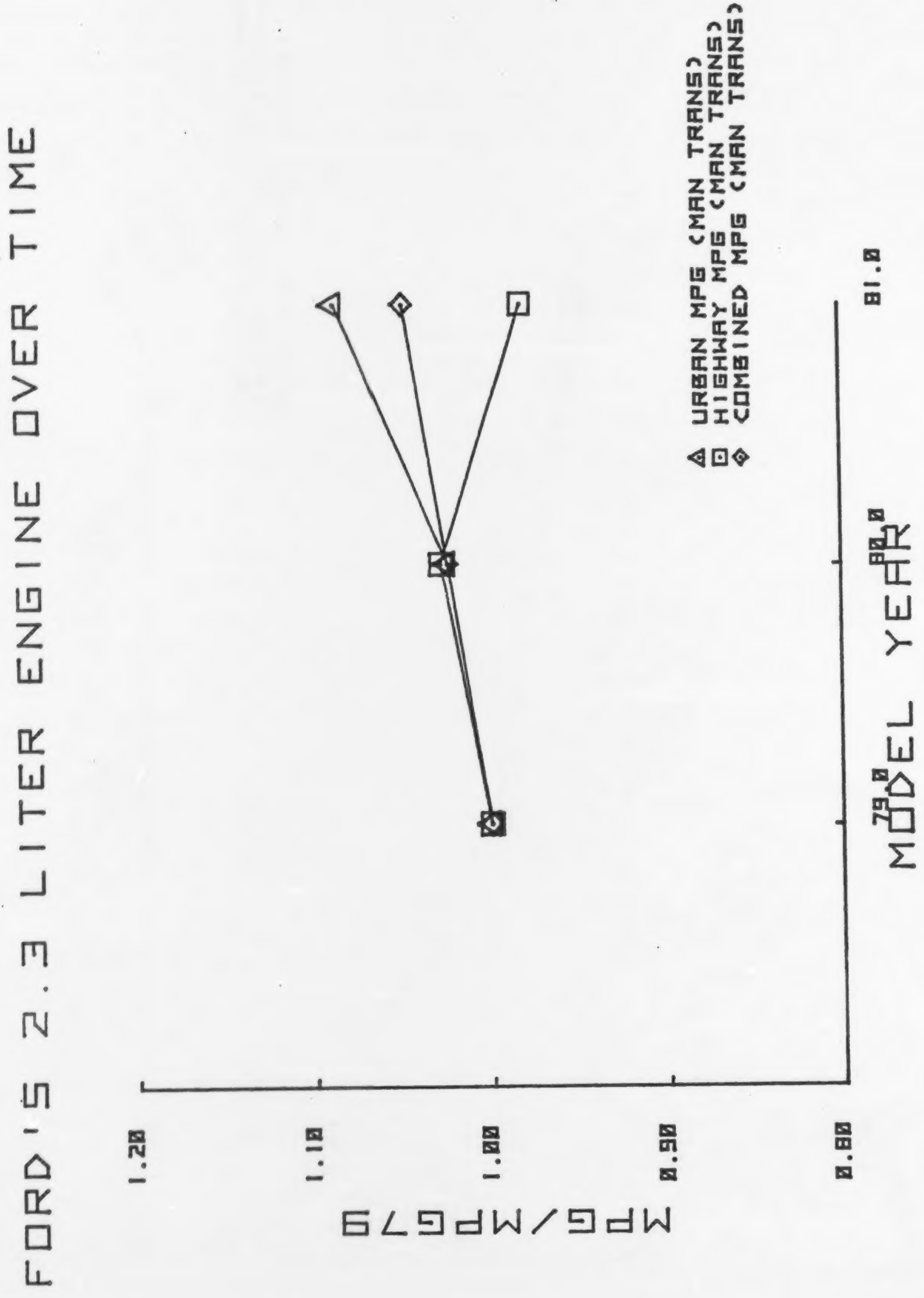
Plots of Emissions and Fuel Economy from Special Engines over Time

Two variable plots of the ratio of the Combined Fuel Economy of each year divided by the Combined Fuel Economy of the corresponding base year (usually 1979) versus each of FTPHC, FTPCO, FTPNOX, and FENOX.

Details of the data used may be found in Tables IV. F-1 through IV. F-5 in Section IV. F.

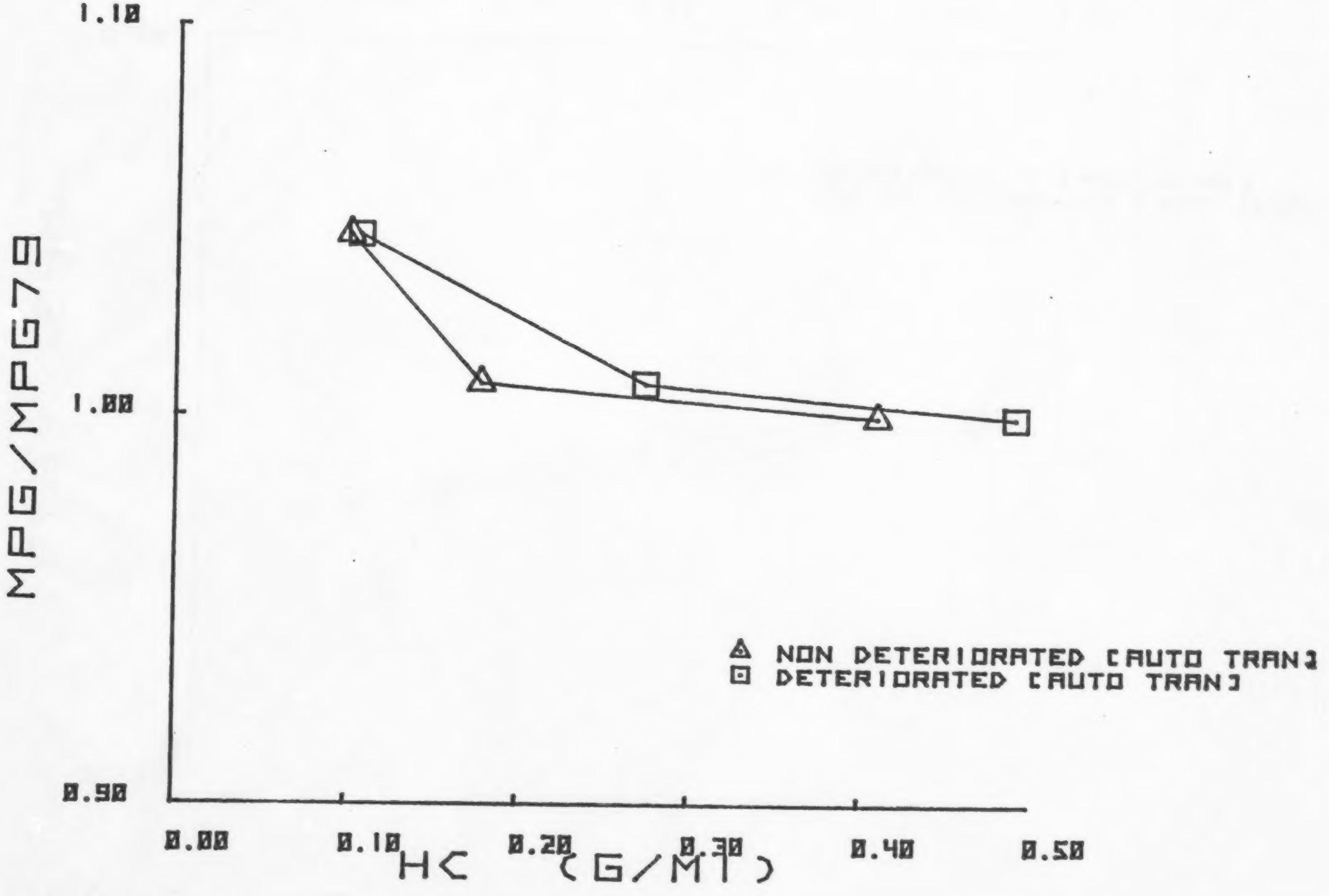
FORD'S 2.3 LITER ENGINE OVER TIME



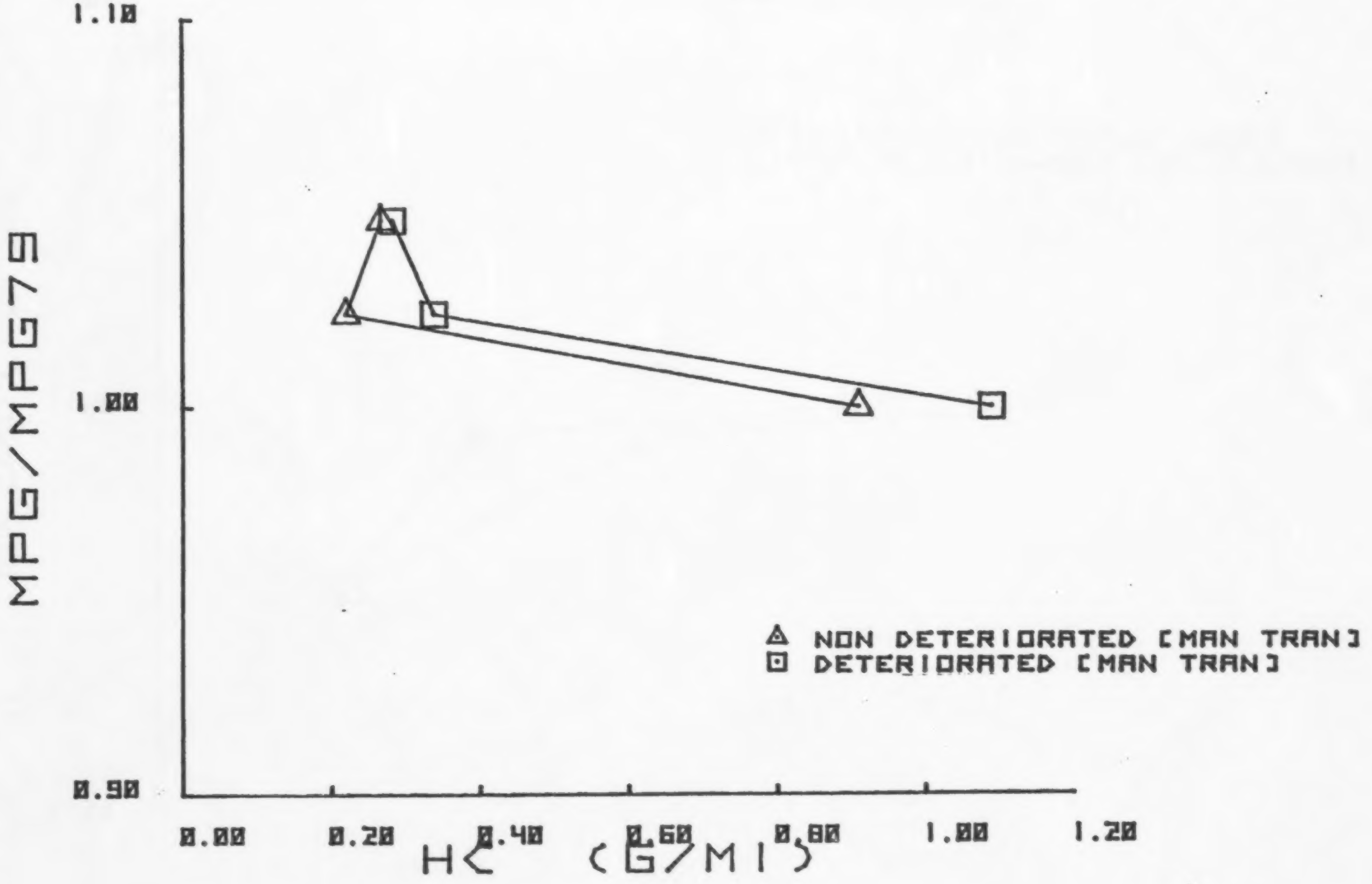


FORD'S 2.3 LITER ENGINE OVER TIME

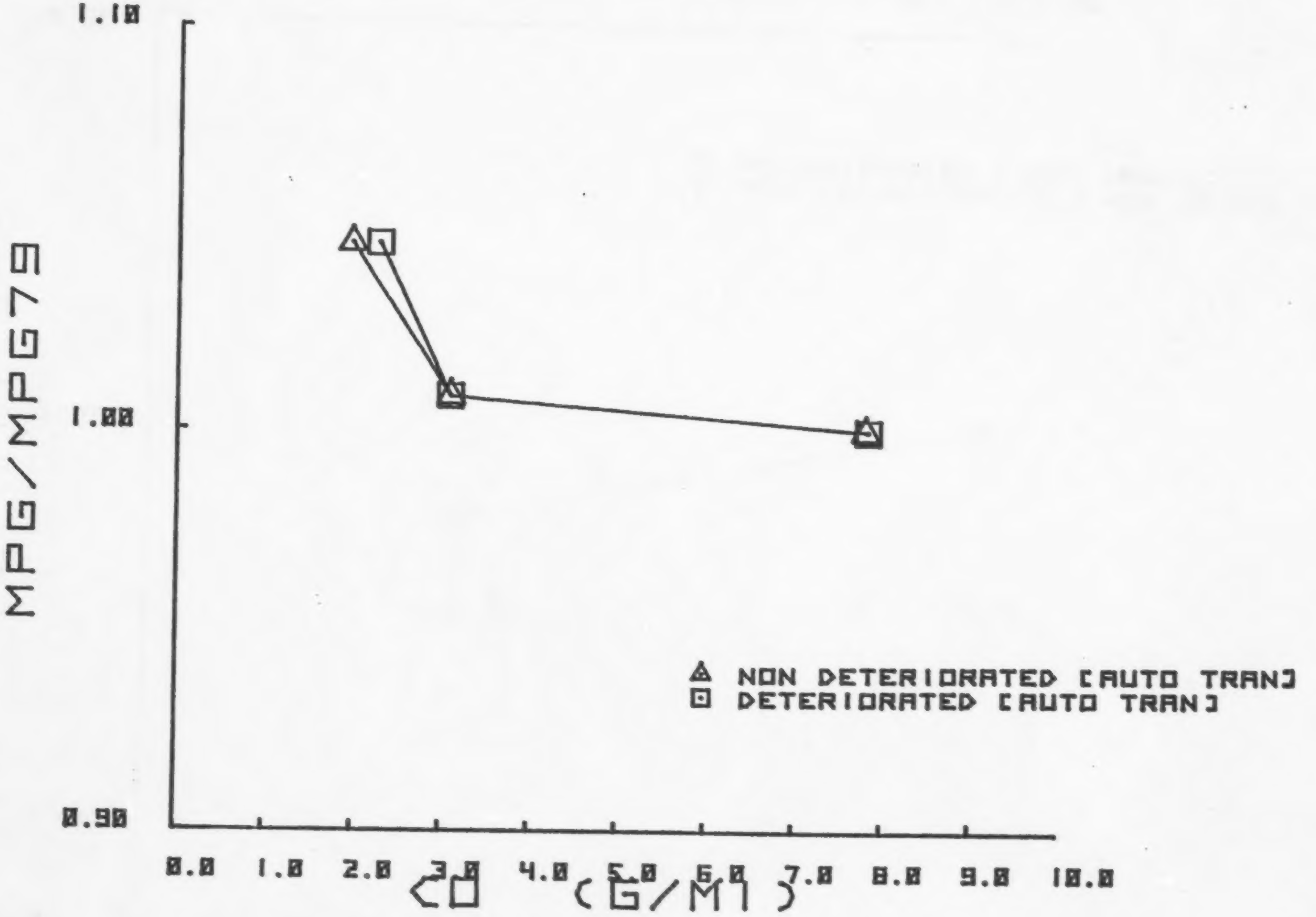
COMBINED MPG VS. URBAN HC
FORD'S 2.3 LITER ENGINE OVER TIME



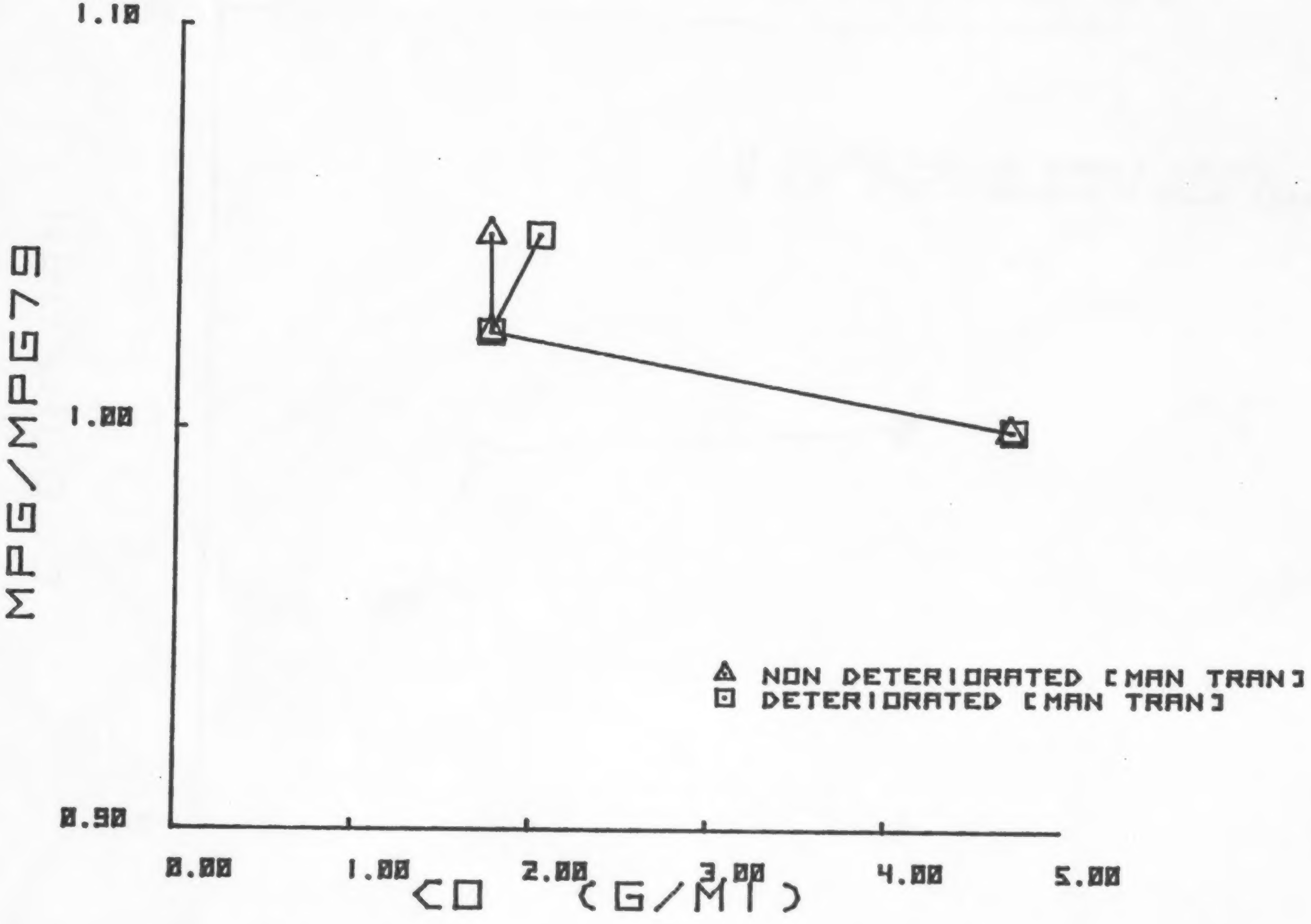
COMBINED MPG VS. URBAN HC
FORD'S 2.3 LITER ENGINE OVER TIME



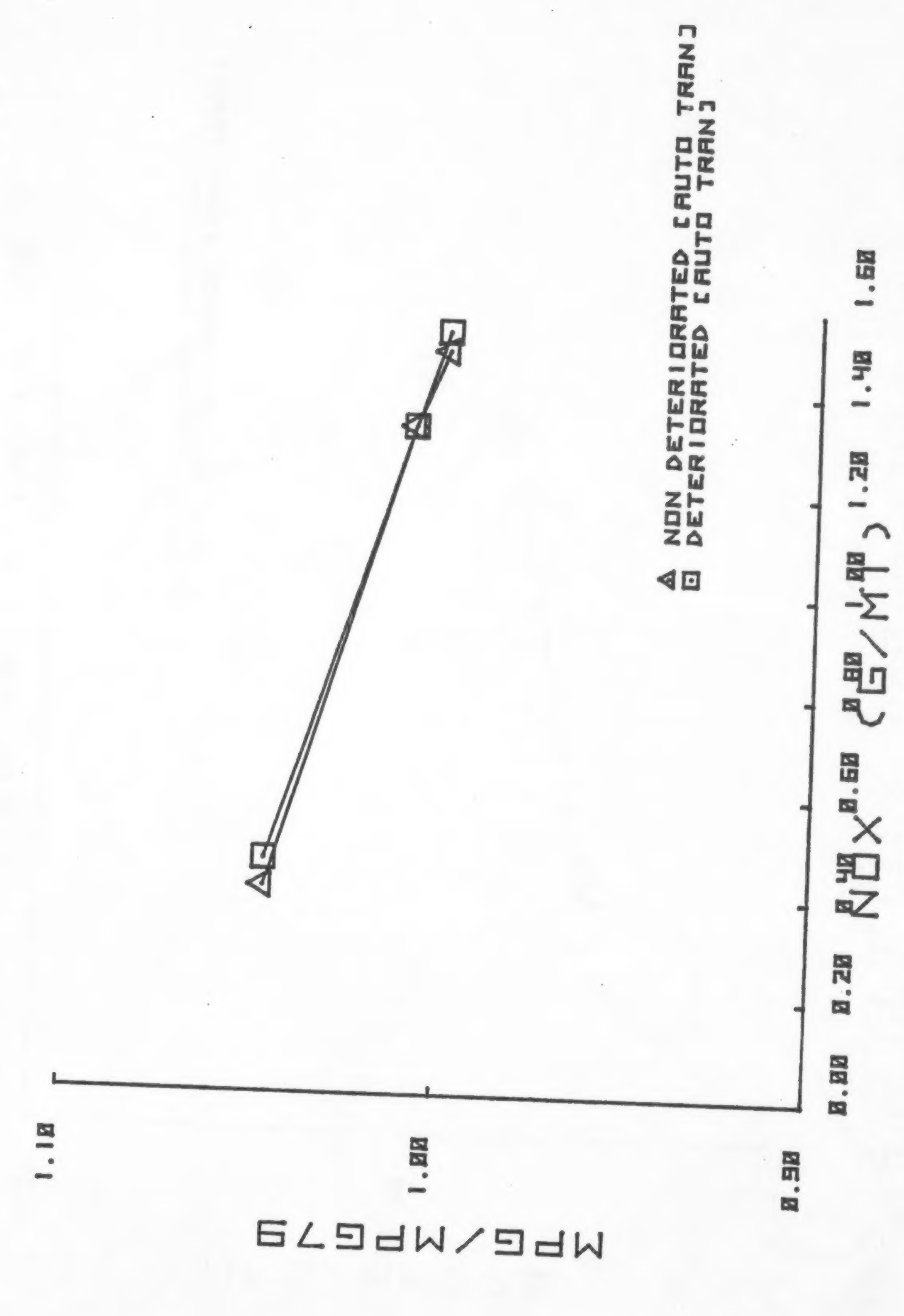
COMBINED MPG VS. URBAN CO
FORD'S 2.3 LITER ENGINE OVER TIME



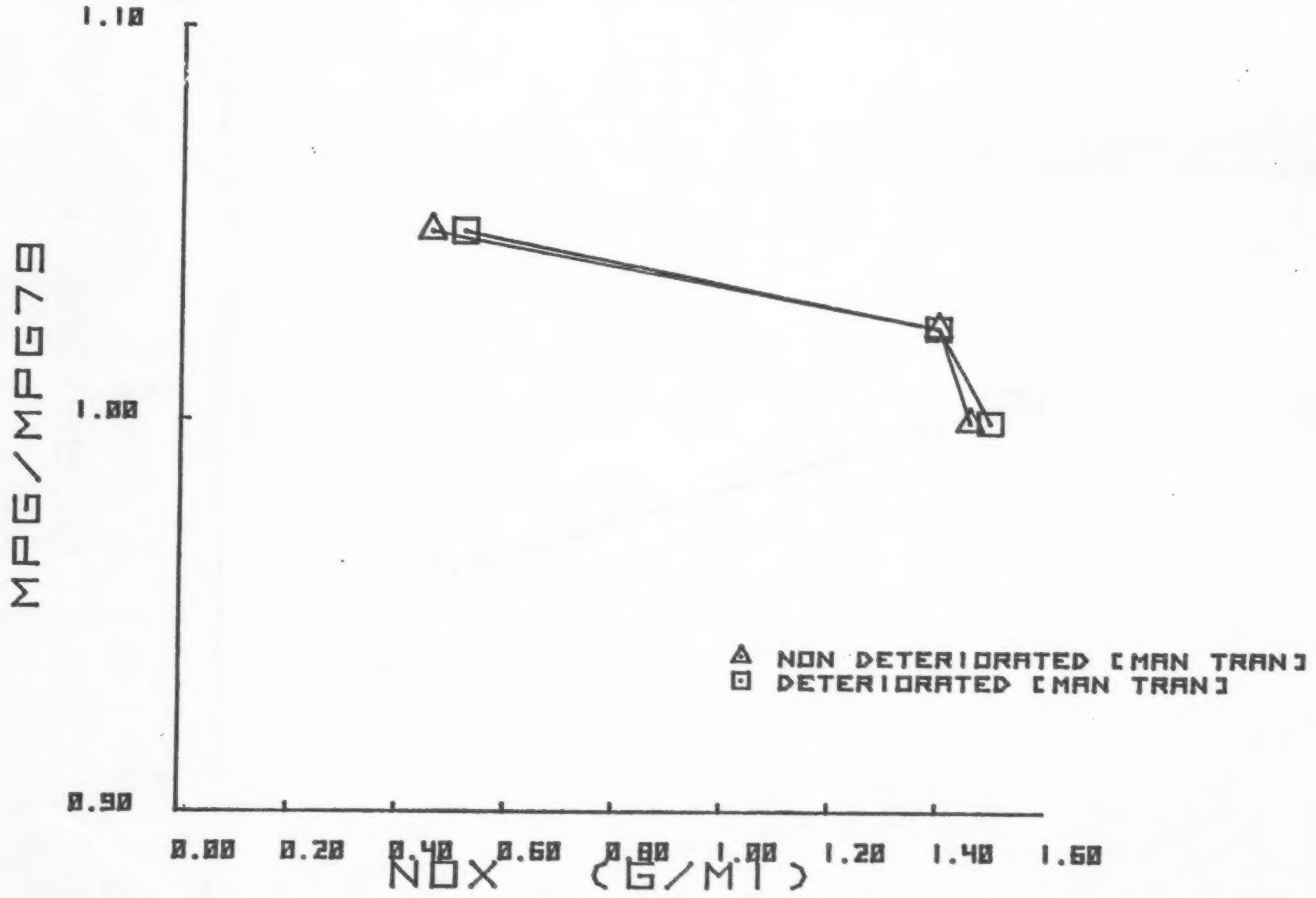
COMBINED MPG VS. URBAN CO
FORD'S 2.3 LITER ENGINE OVER TIME



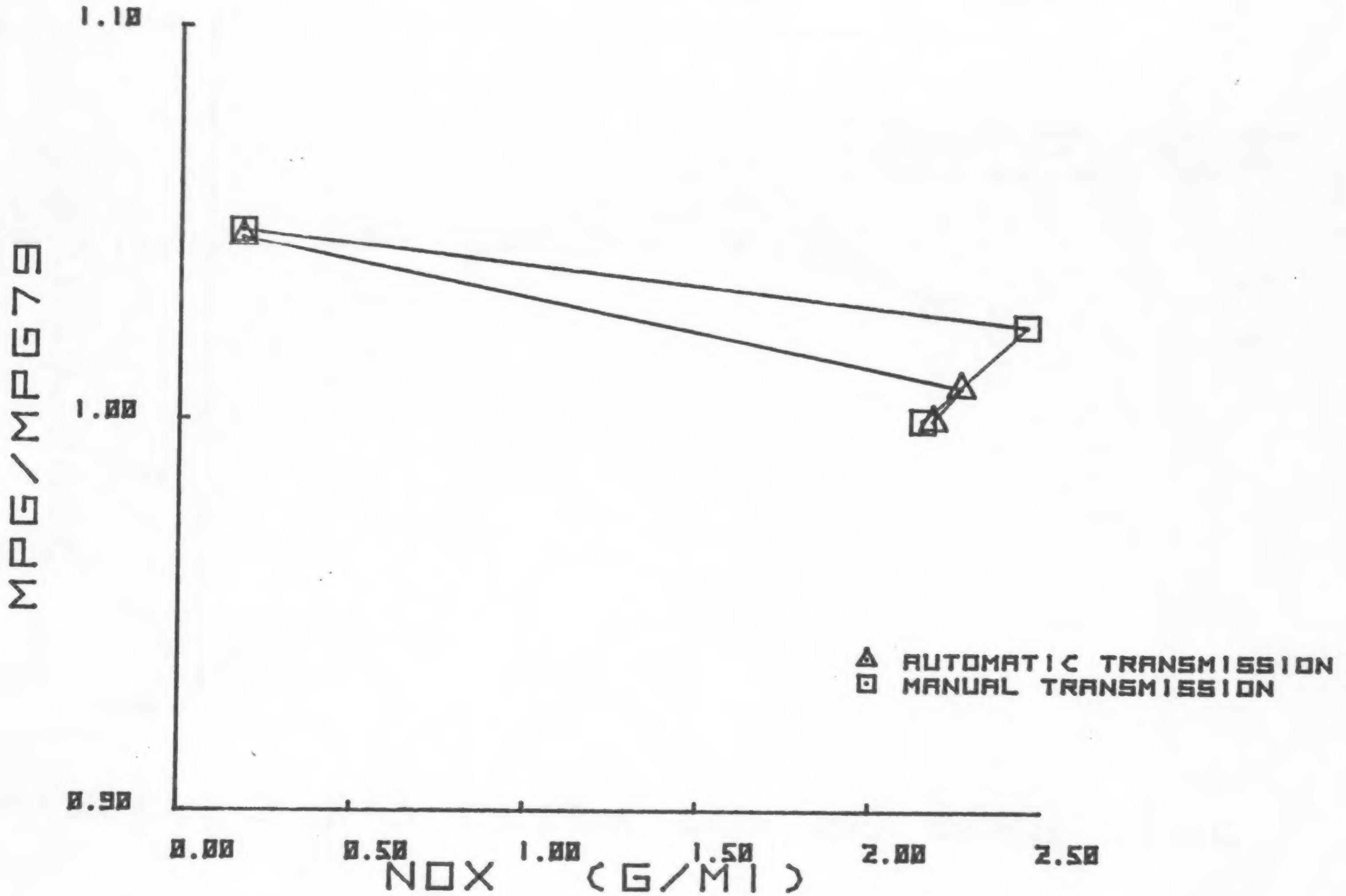
COMBINED MPG VS URBAN NOX
FORD'S 2.3 LITER ENGINE OVER TIME



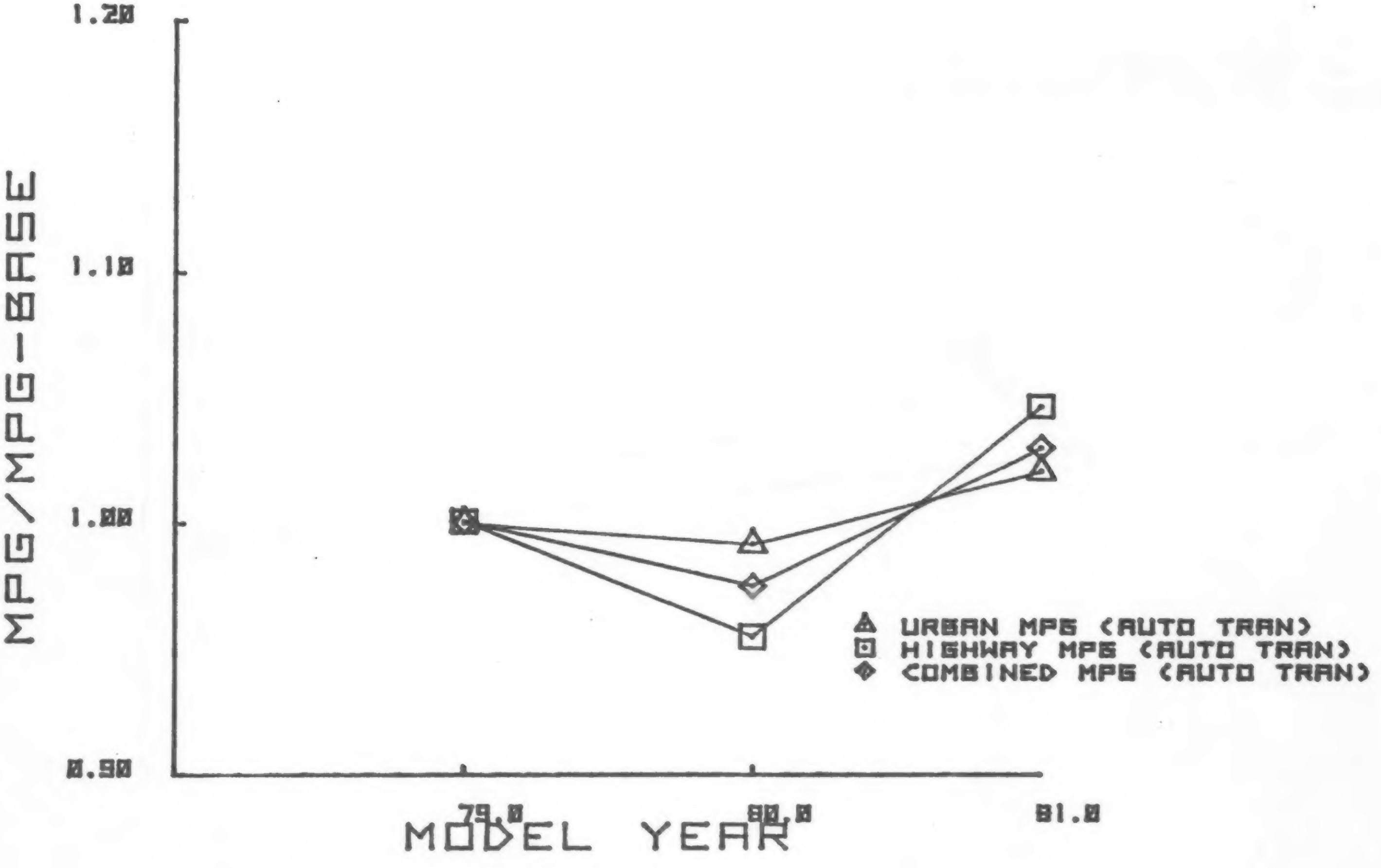
COMBINED MPG VS. URBAN NOX
FORD'S 2.3 LITER ENGINE OVER TIME



COMBINED MPG VS. HIGHWAY NOX
FORD'S 2.3 LITER ENGINE OVER TIME



CHRYSLER'S 1.7 LITER ENGINE OVER TIME



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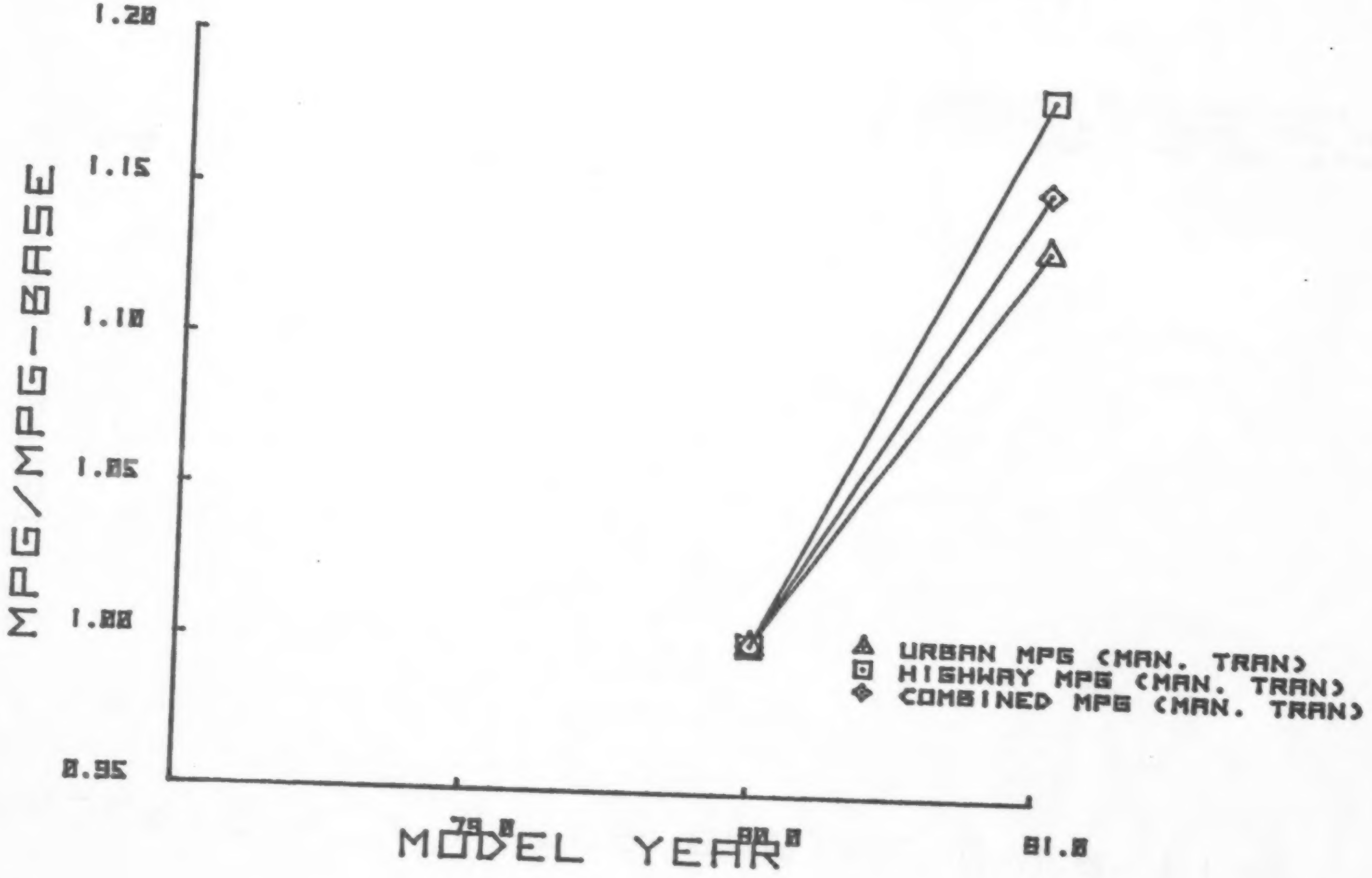

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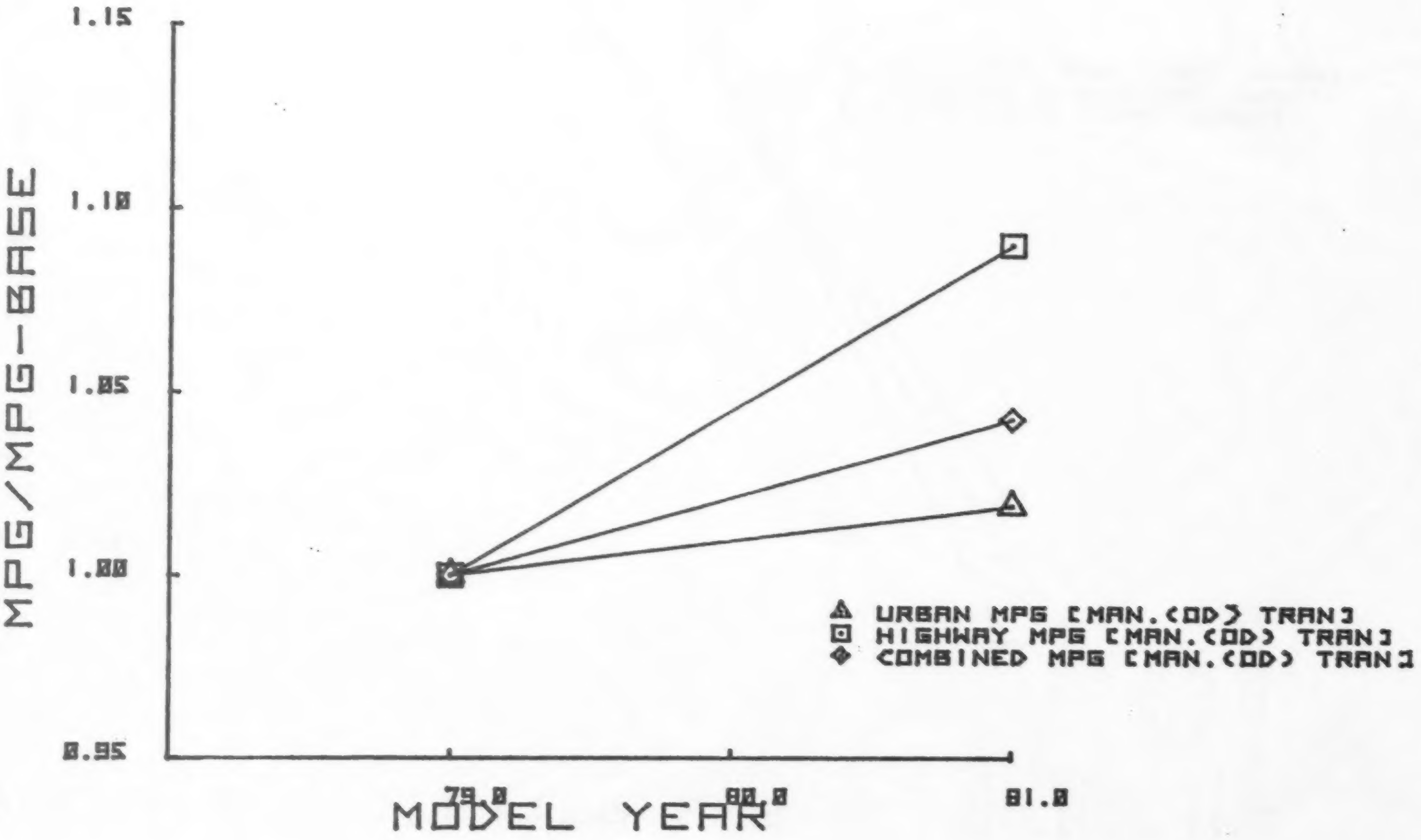
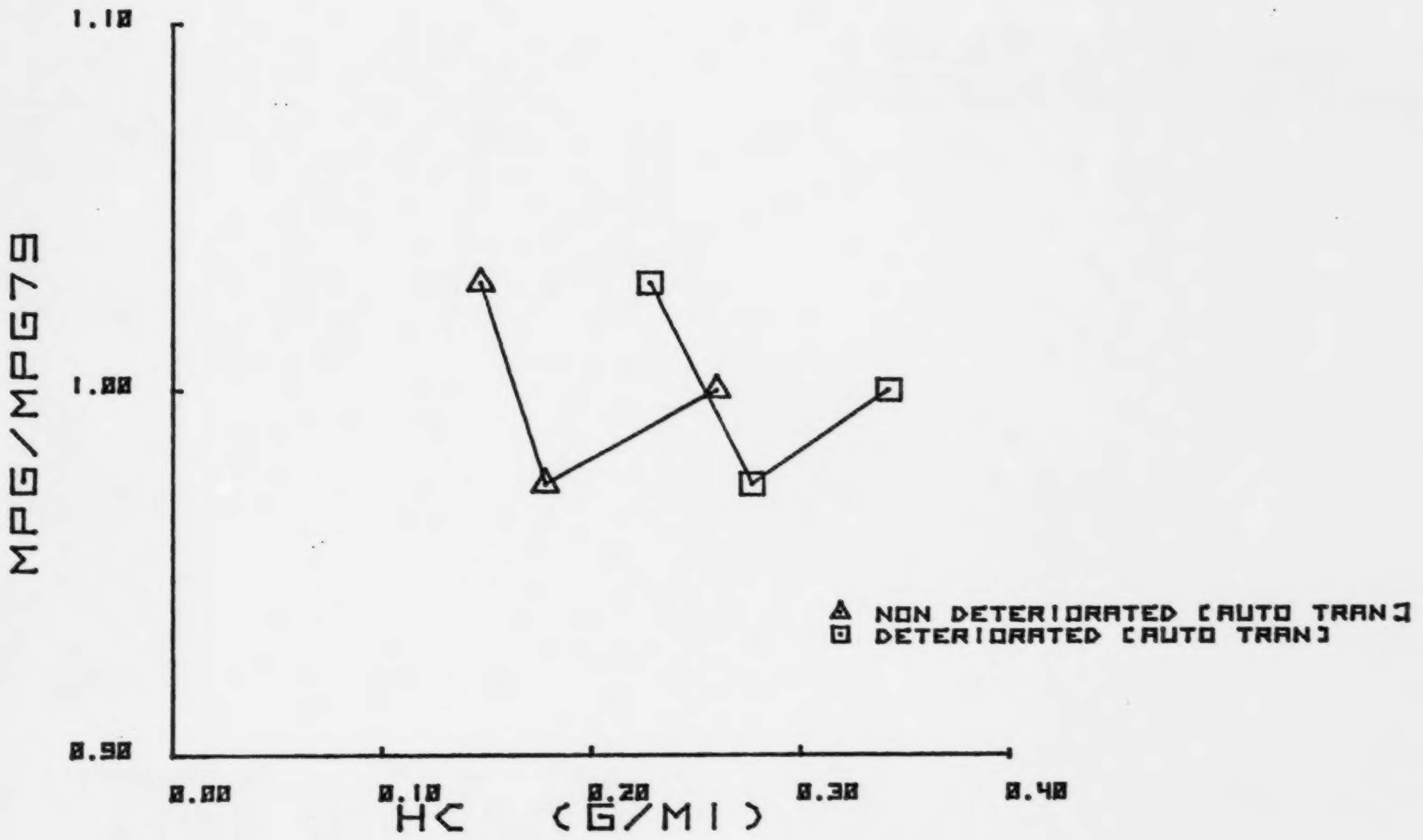
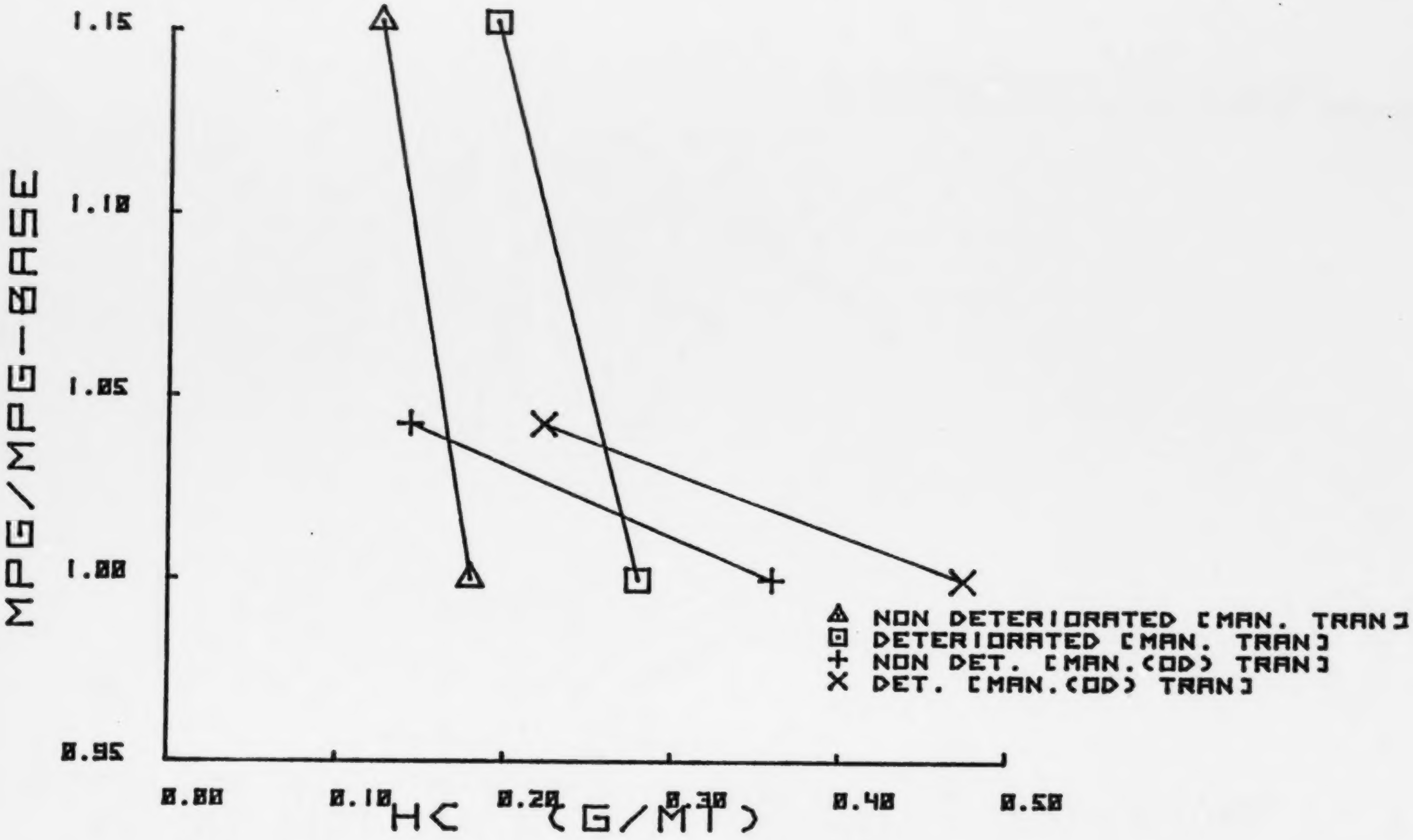


COMBINED MPG VS. URBAN HC
CHRYSLER'S 1.7 LITER ENGINE OVER TIME



COMBINED MPG VS. URBAN HC
CHRYSLER'S 1.7 LITER ENGINE OVER TIME



COMBINED MPG VS. URBAN CO
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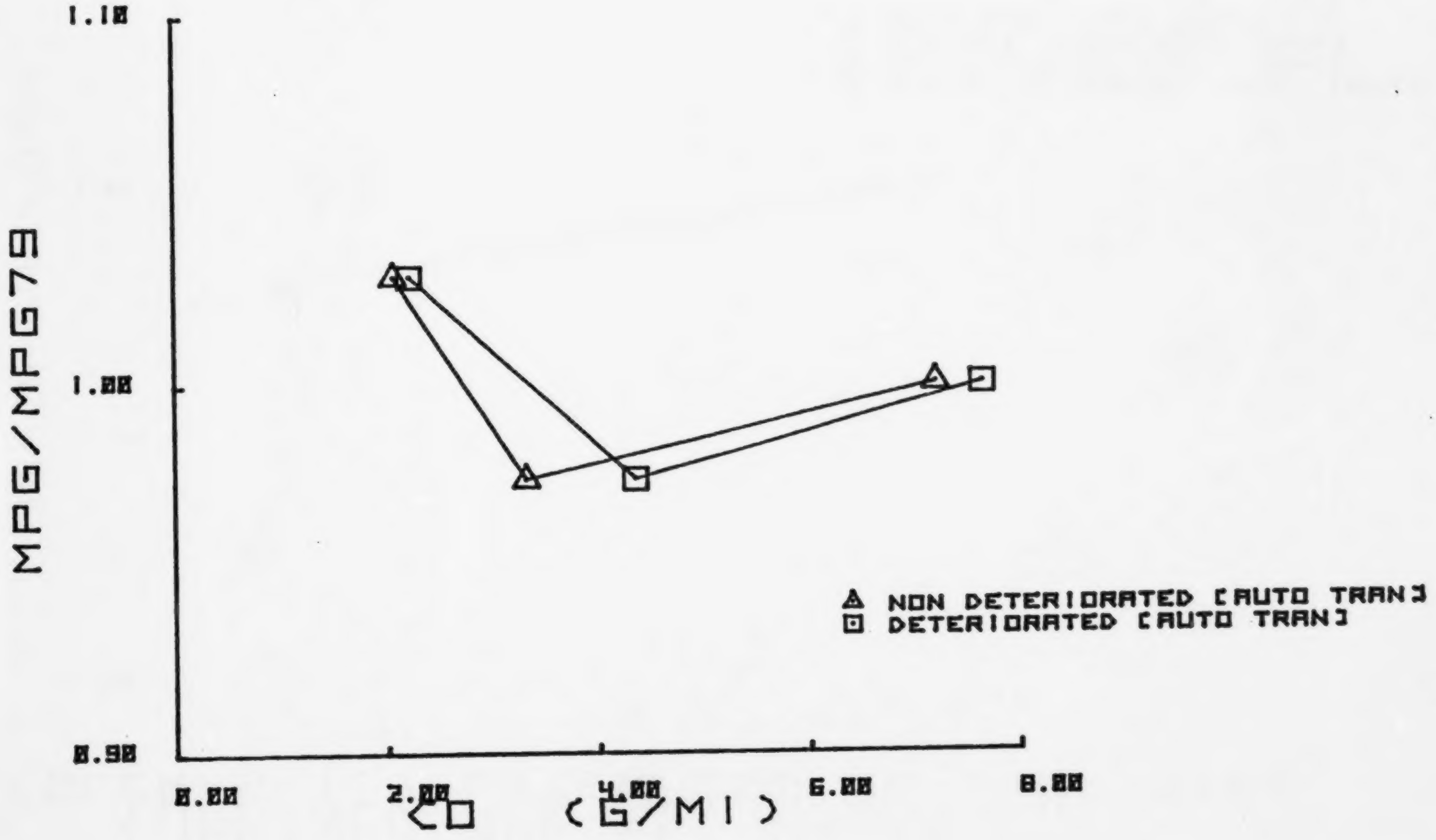
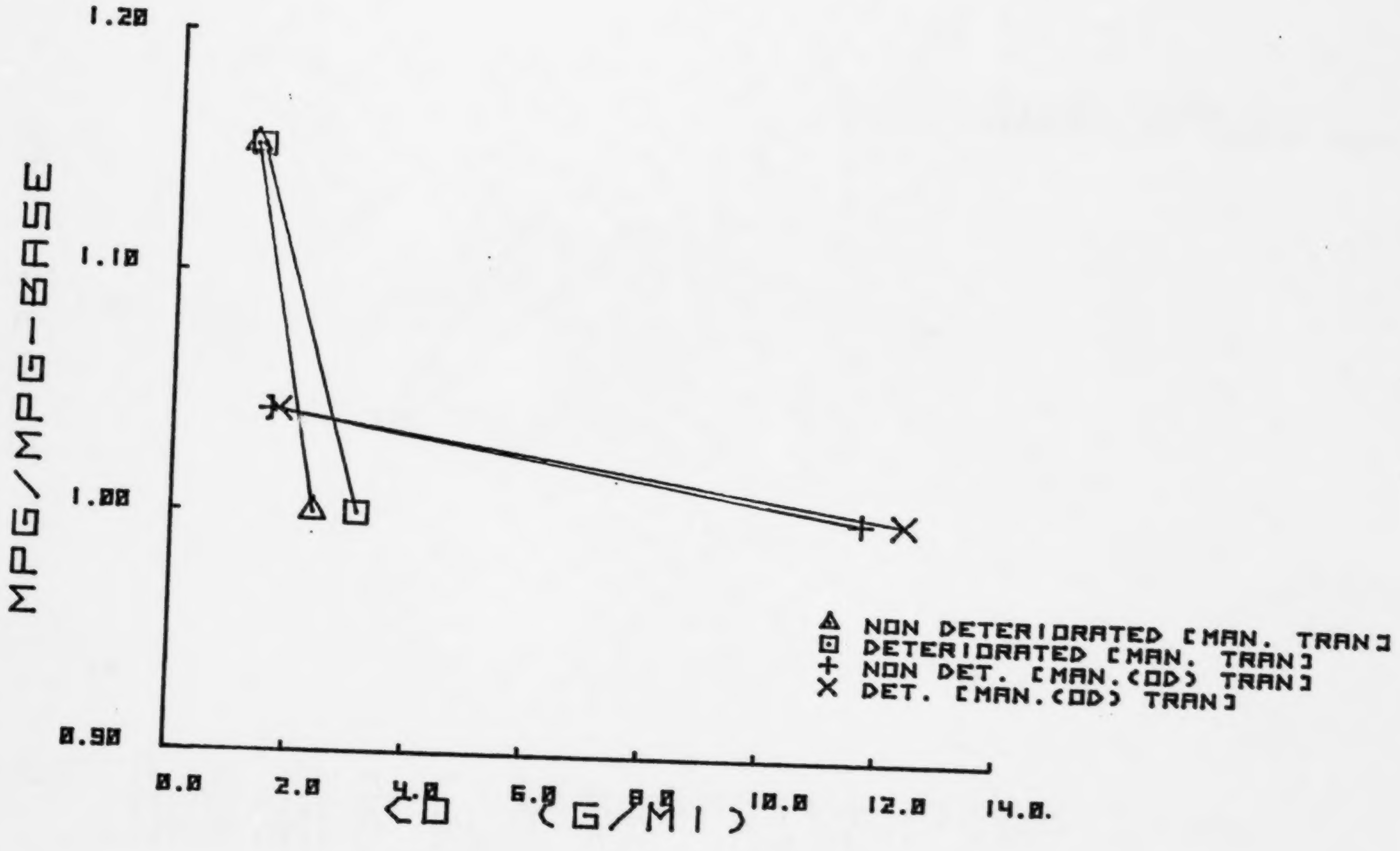
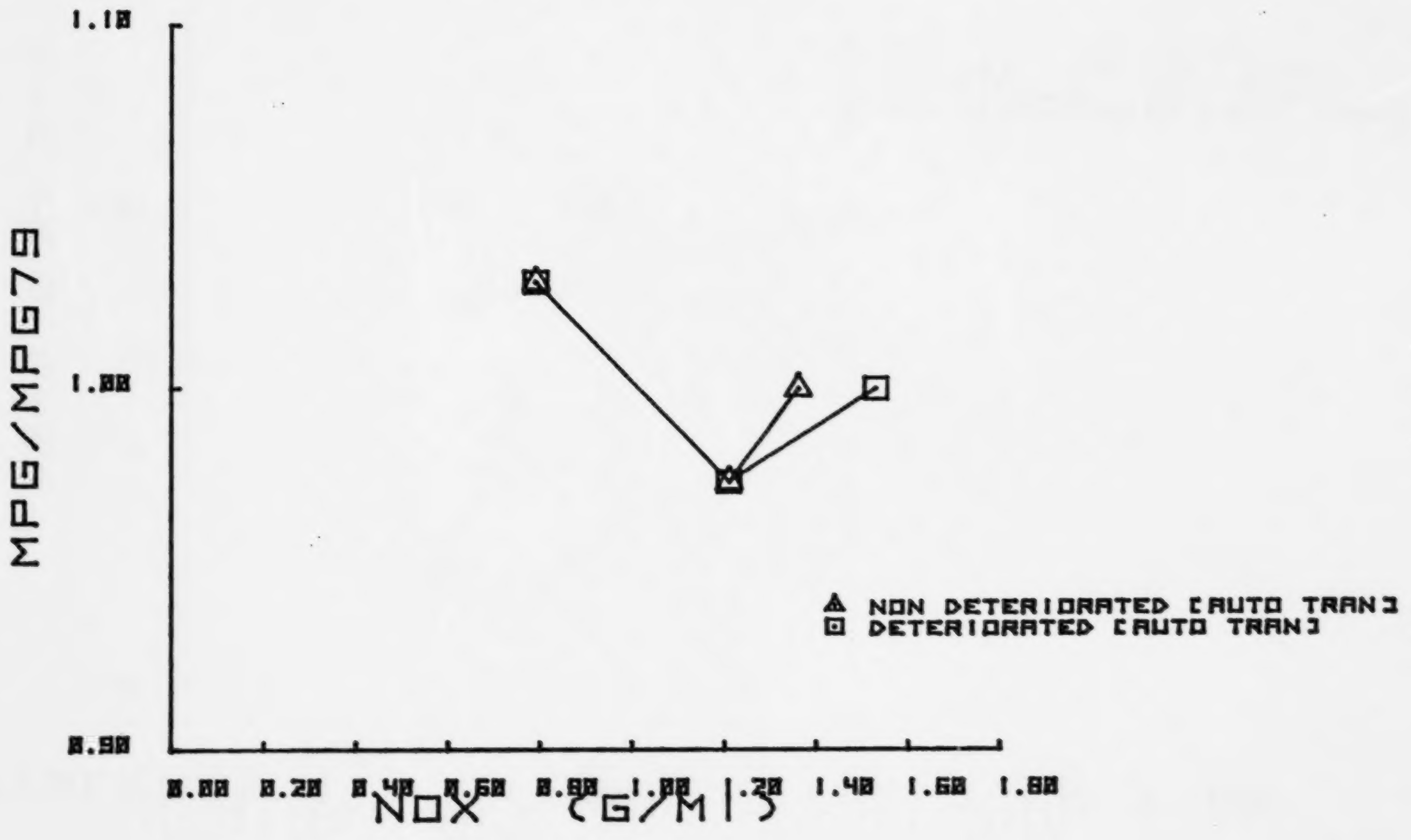


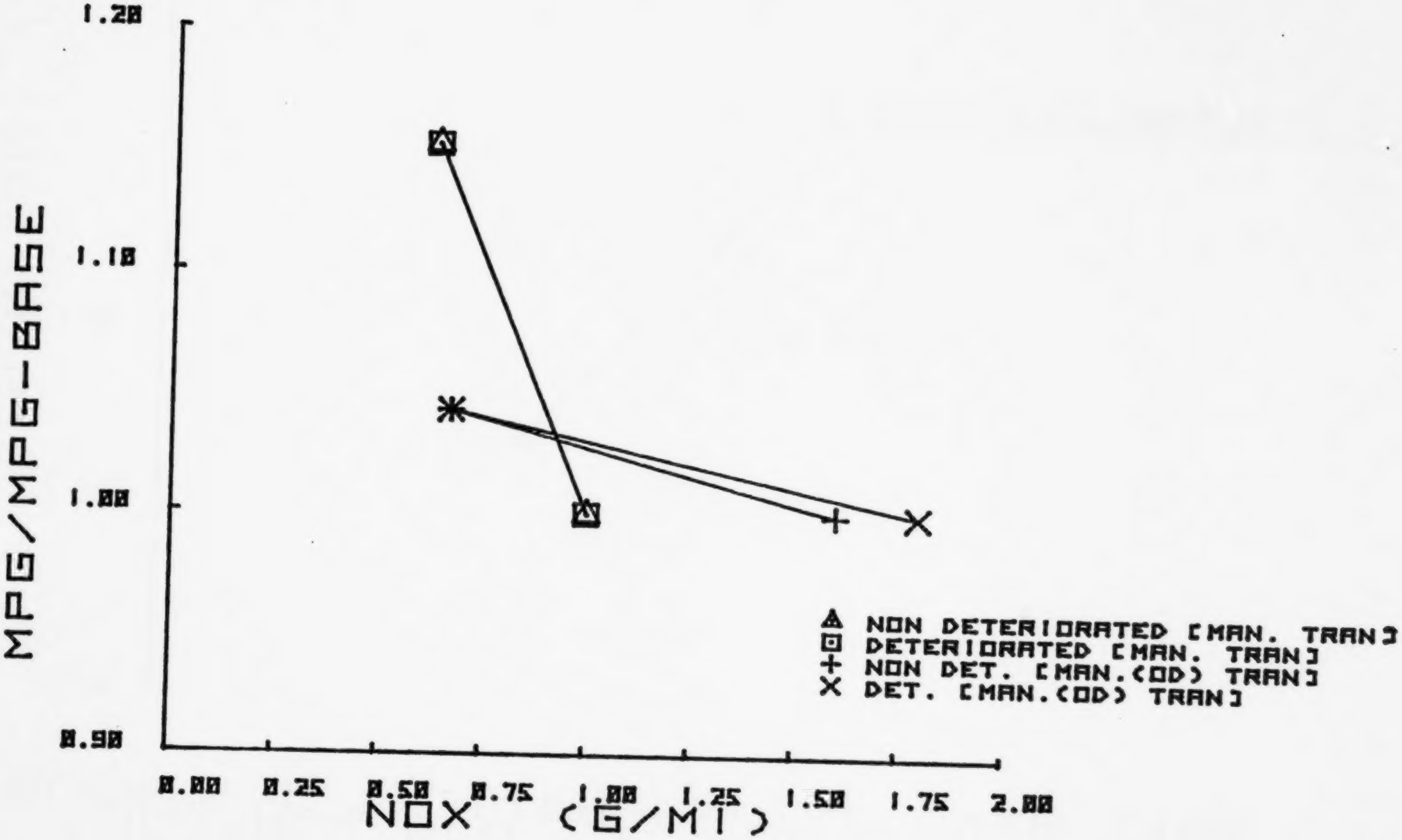
COMBINED MPG VS. URBAN CO
CHRYSLER'S 1.7 LITER ENGINE OVER TIME



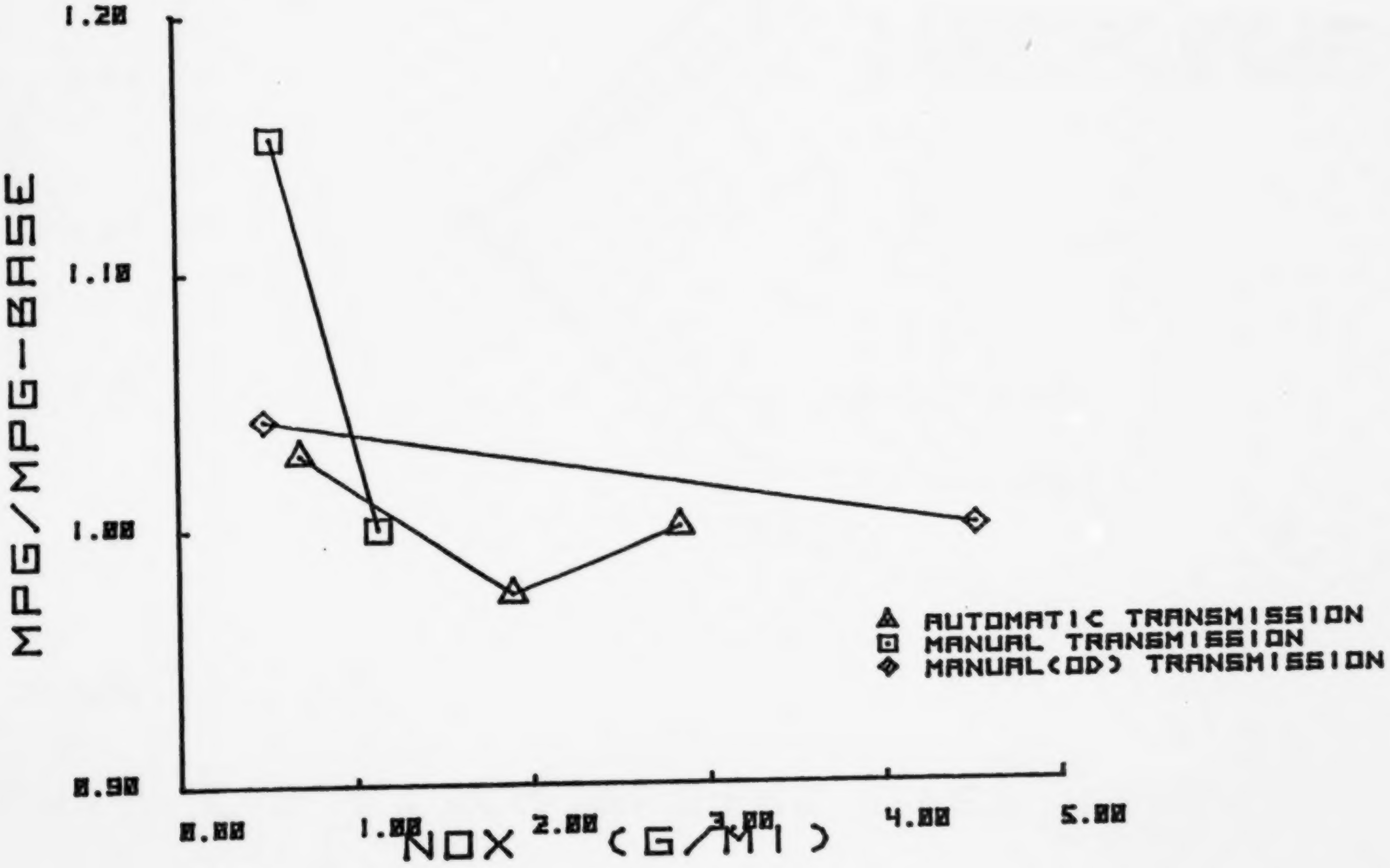
COMBINED MPG VS. URBAN NOX
CHRYSLER'S 1.7 LITER ENGINE OVER TIME



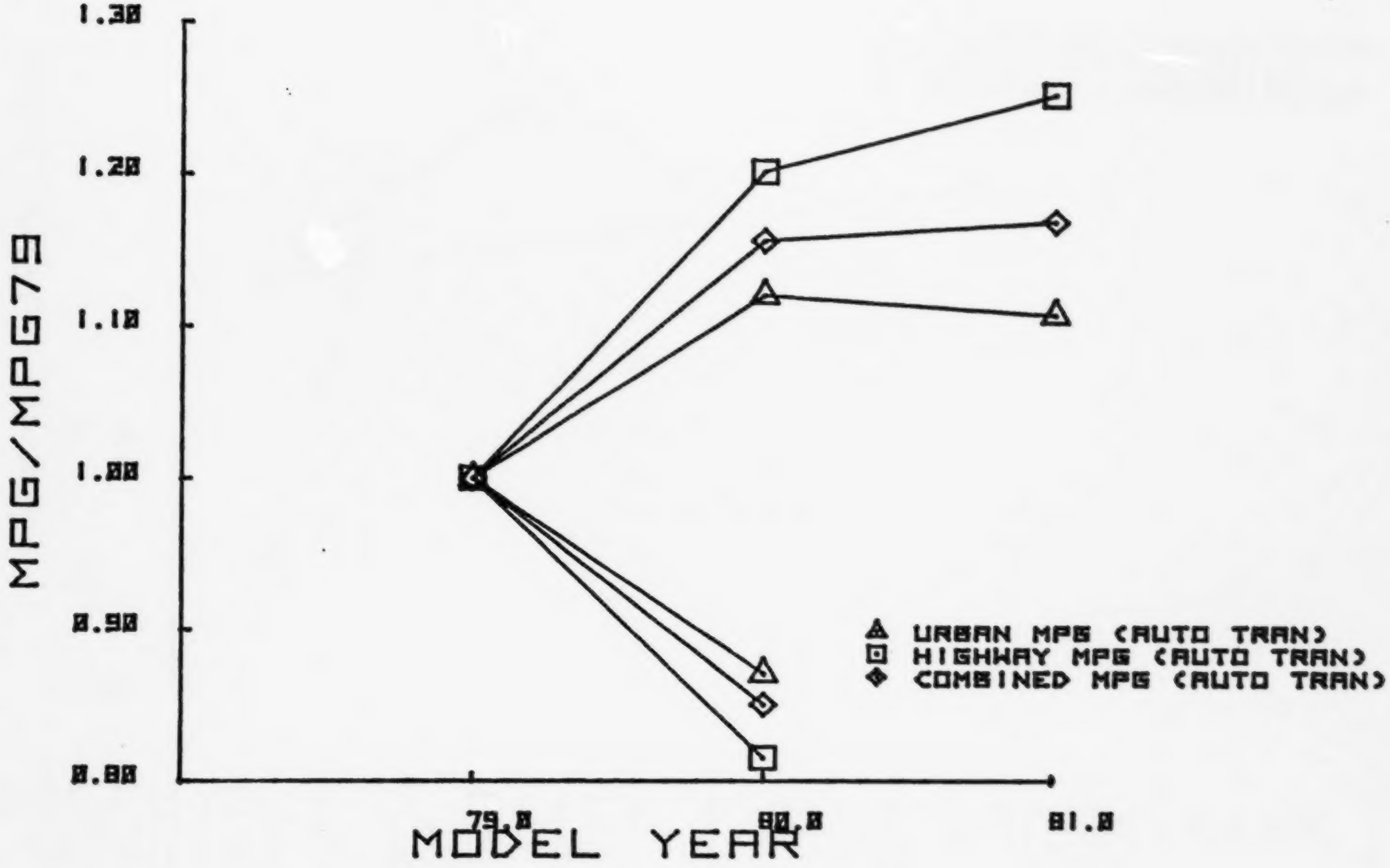
COMBINED MPG VS. URBAN NOX
CHRYSLER'S 1.7 LITER ENGINE OVER TIME



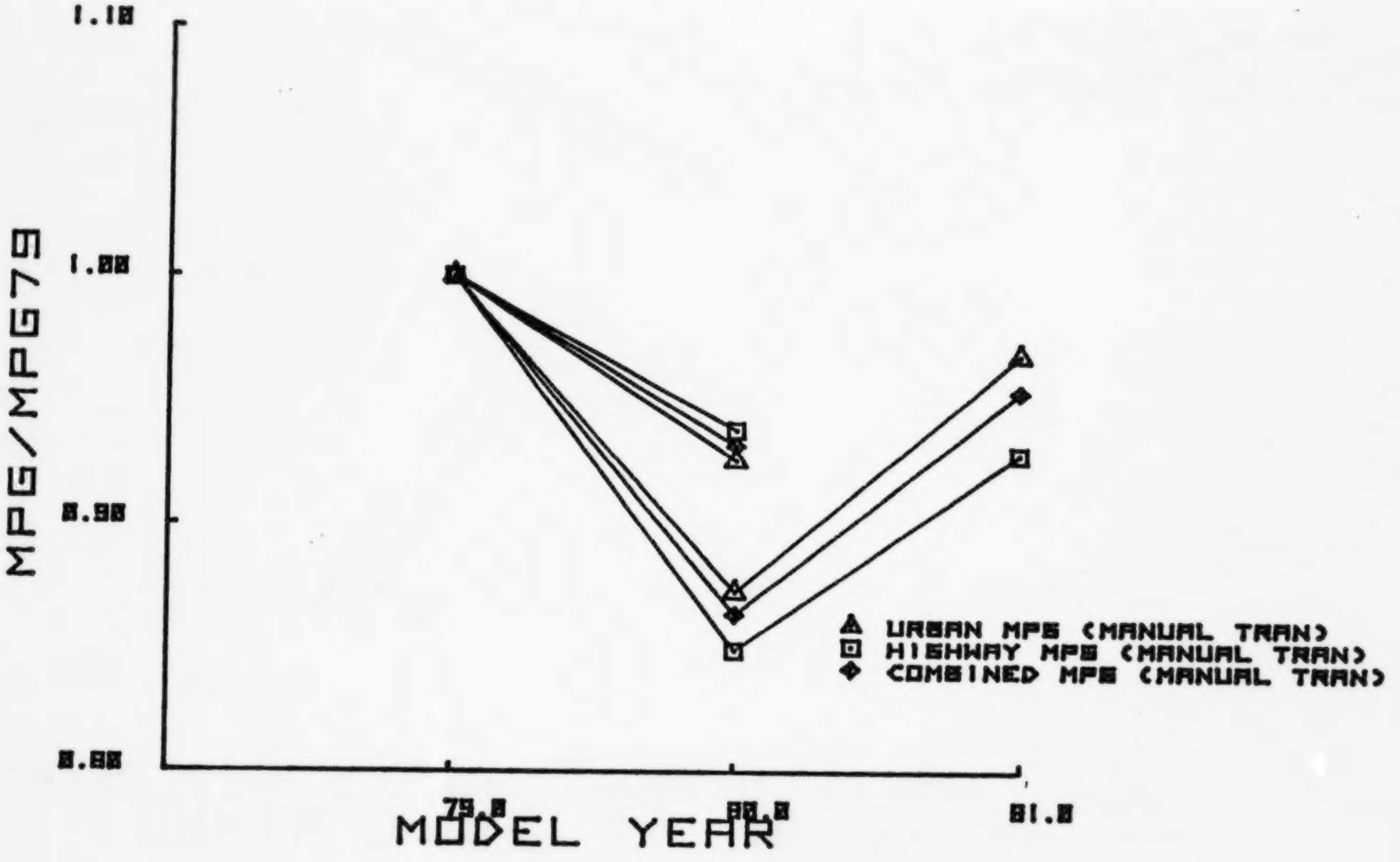
COMBINED MPG VS. HIGHWAY NOX
CHRYSLER'S 1.7 LITER ENGINE OVER TIME



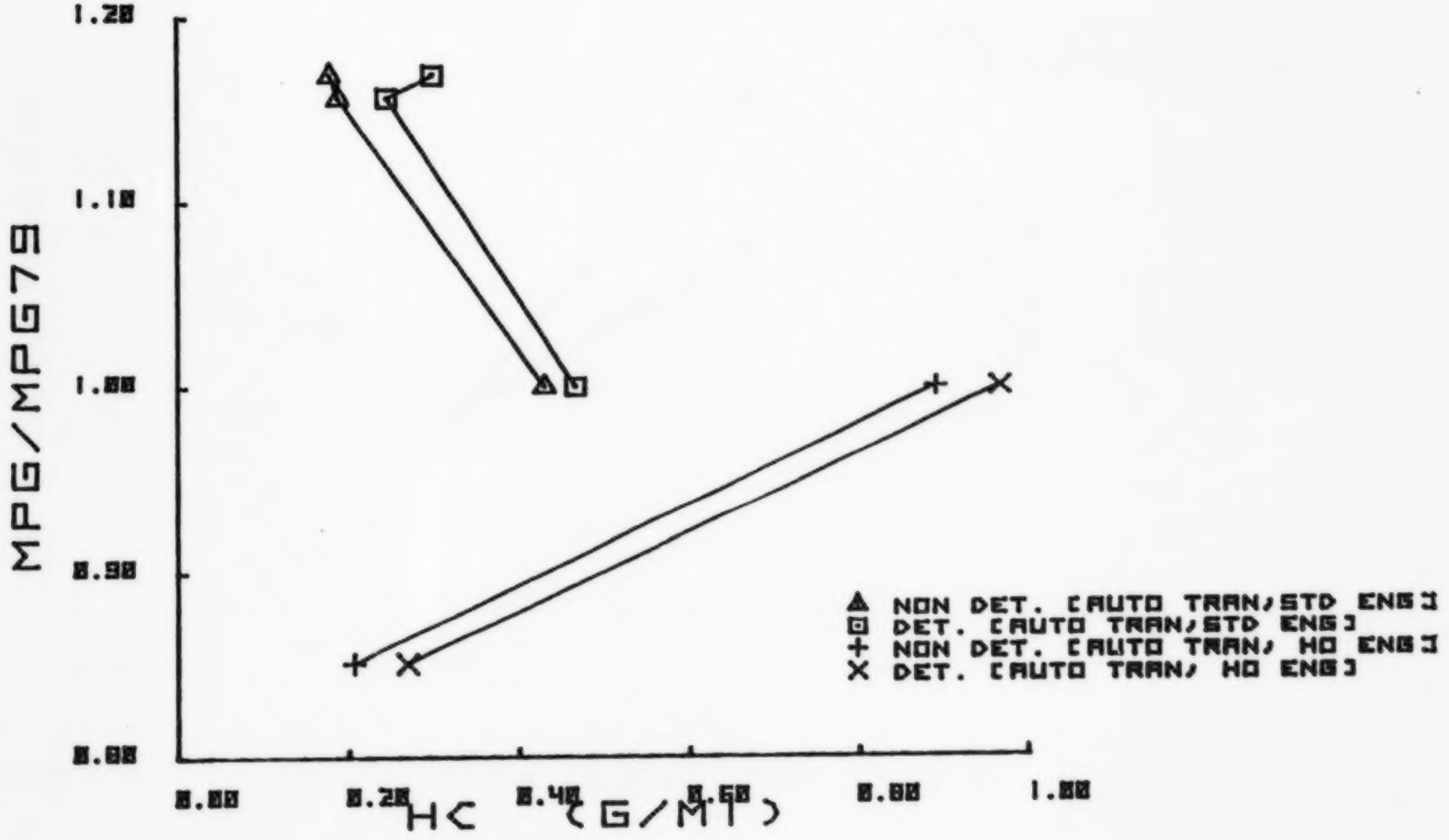
GM'S 1.6 LITER ENGINE OVER TIME



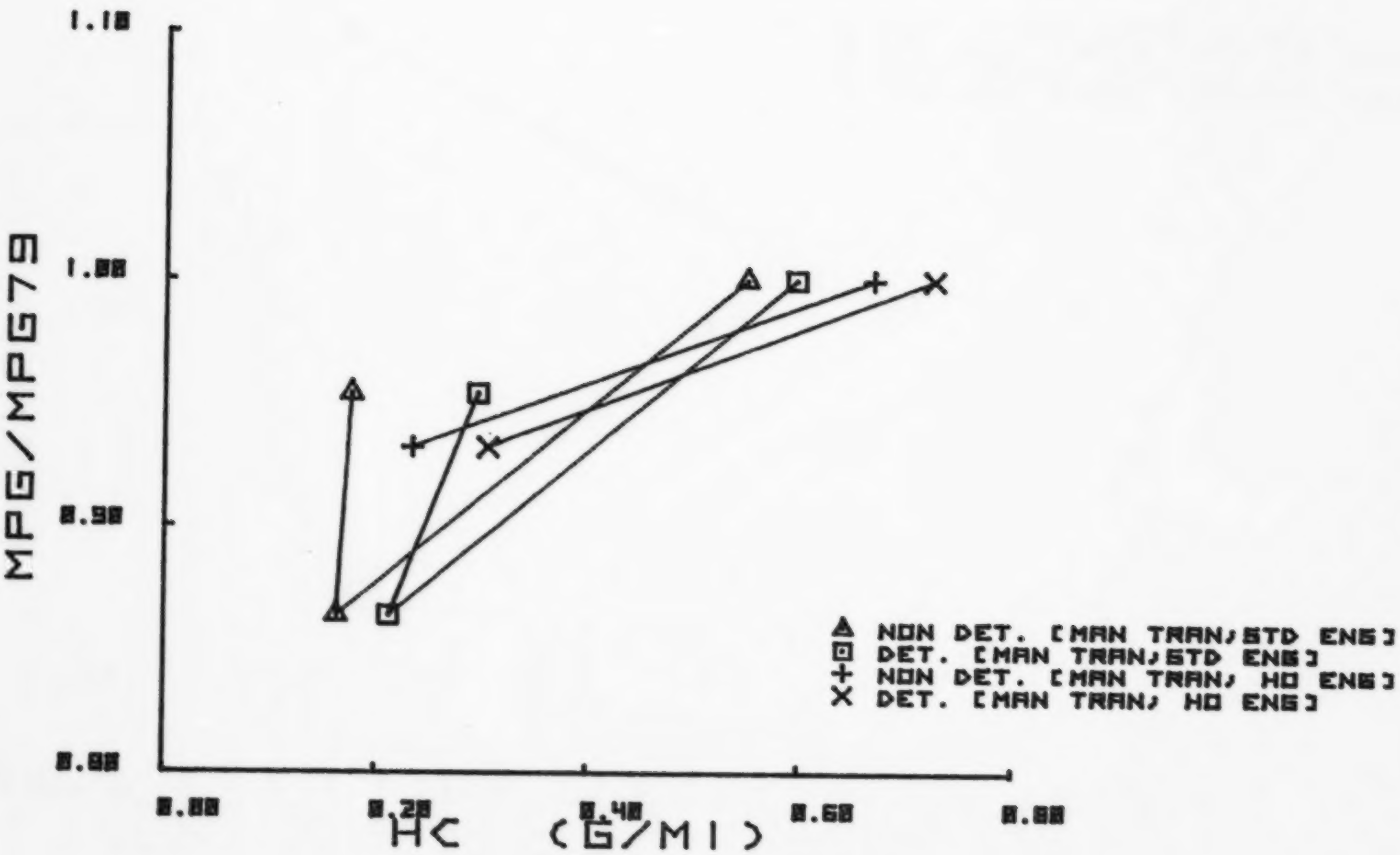
GM'S 1.6 LITER ENGINE OVER TIME

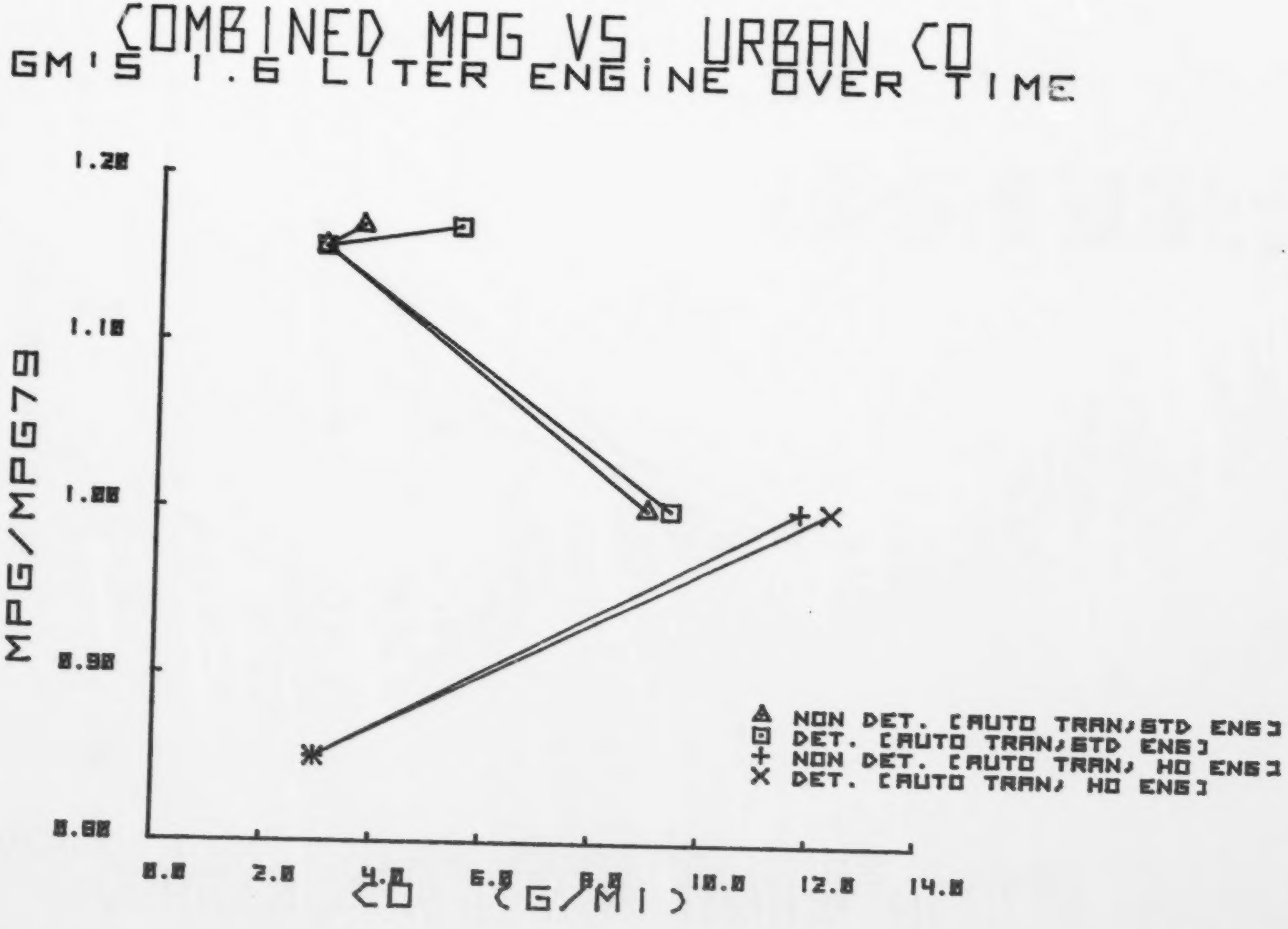


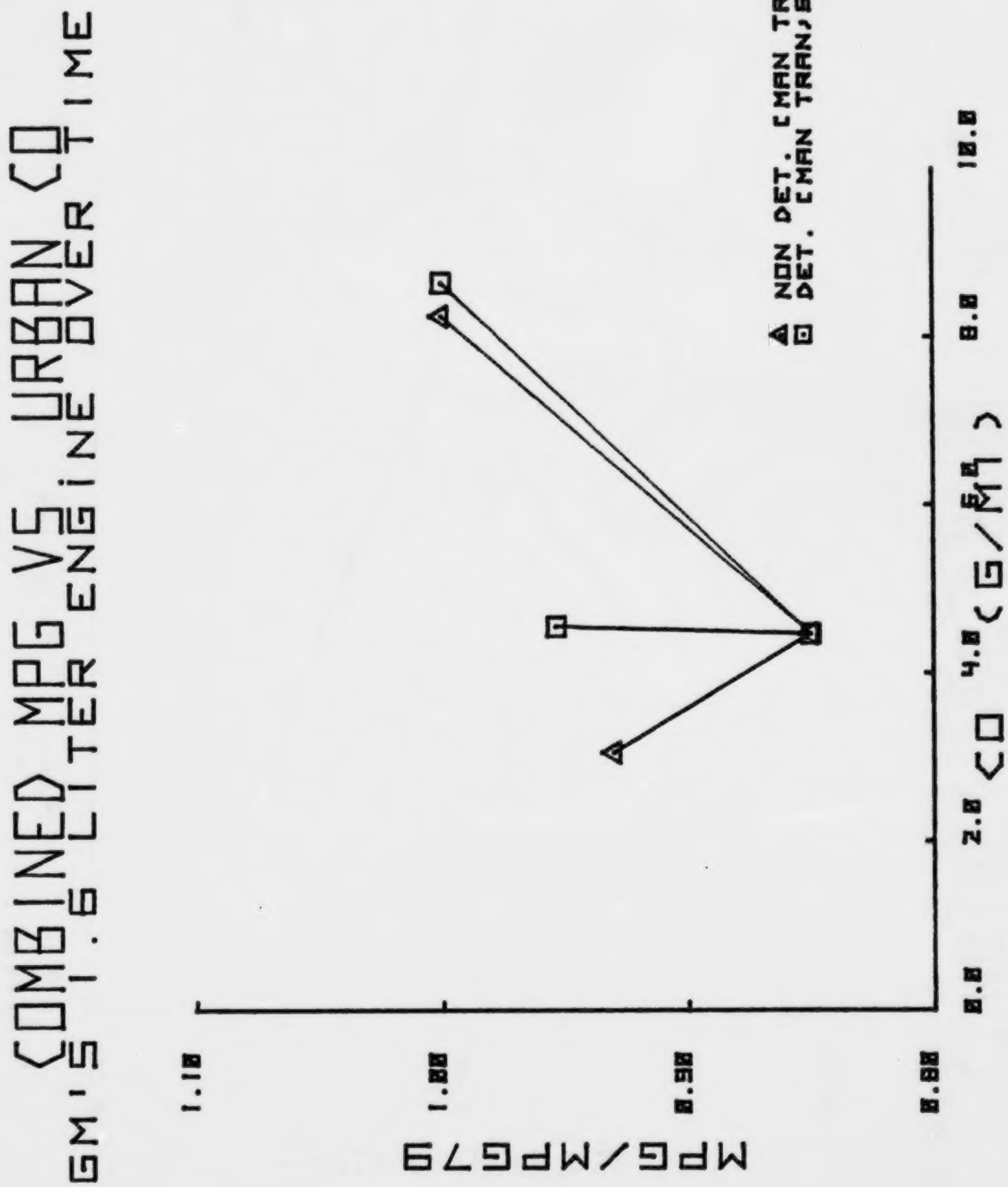
COMBINED MPG VS. URBAN HC
GM'S 1.6 LITER ENGINE OVER TIME

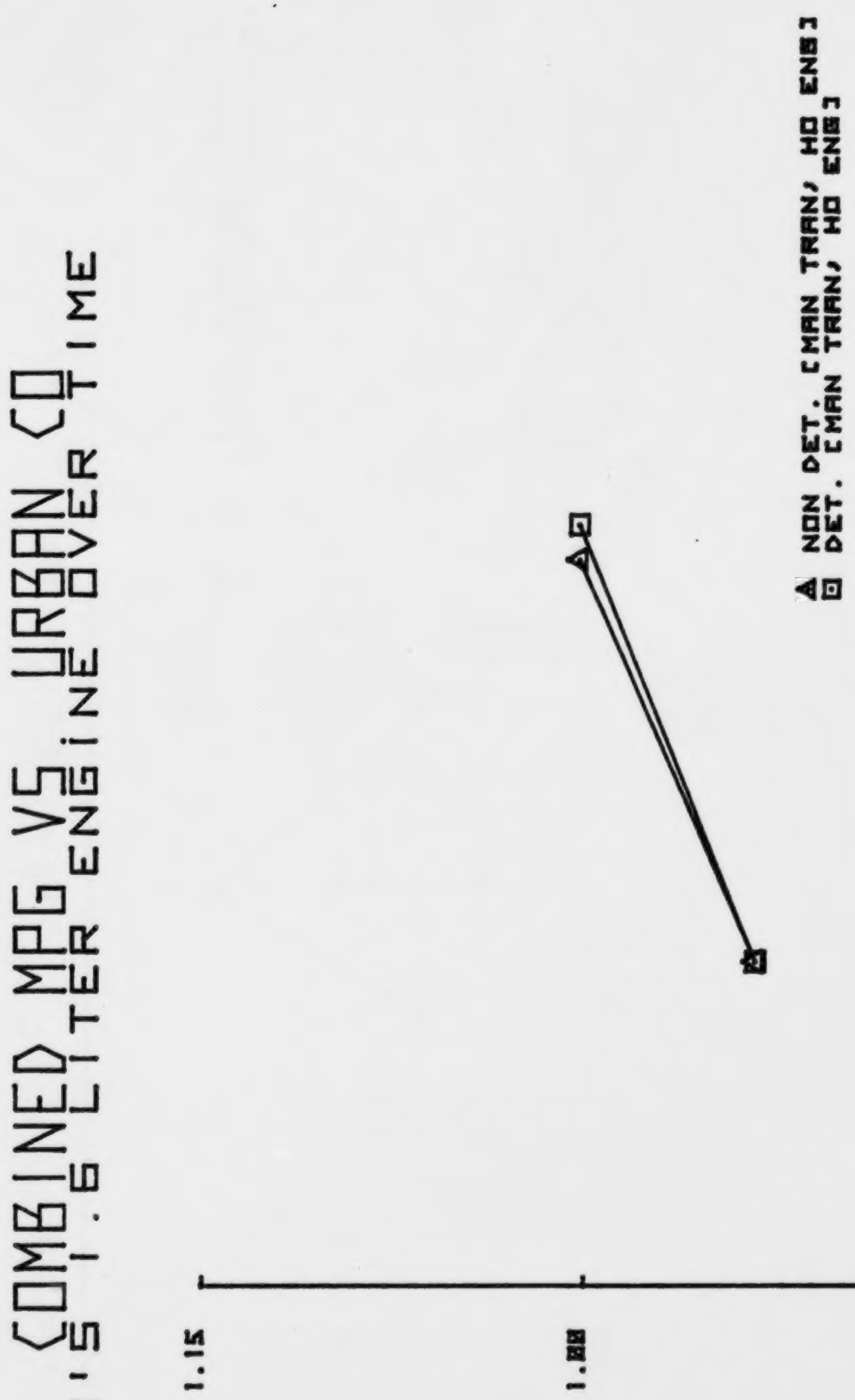


COMBINED MPG VS URBAN HC
GM'S 1.6 LITER ENGINE OVER TIME

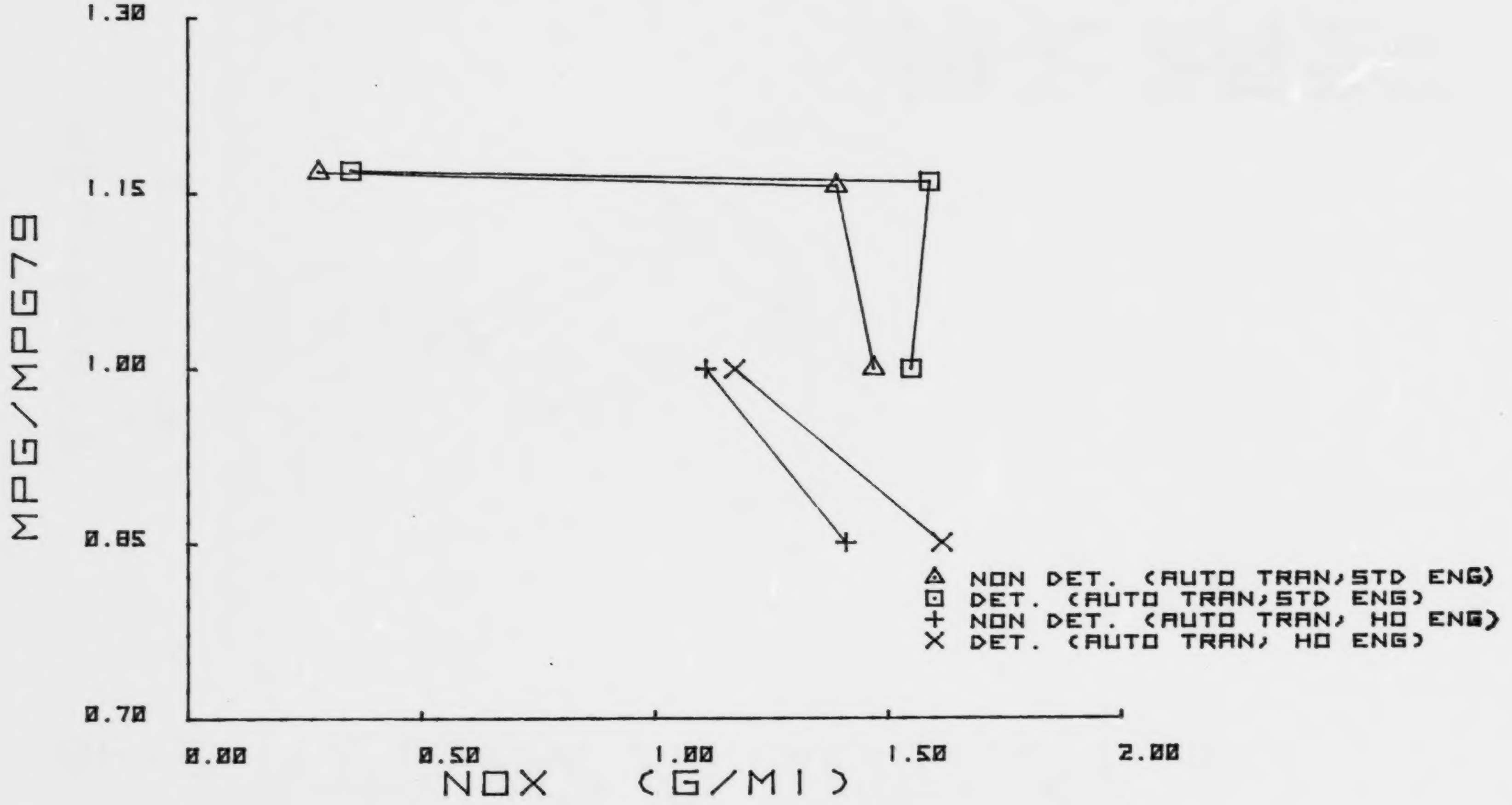



COMBINED MPG VS URBAN CO
GM'S 1.6 LITER ENGINE OVER TIME
MPG/MPG79
1.20
1.10
1.00
0.90
0.80
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
CO (G/MI)
△ NON DET. [AUTO TRAN, STD ENG]
⊡ DET. [AUTO TRAN, STD ENG]
+ NON DET. [AUTO TRAN, HD ENG]
× DET. [AUTO TRAN, HD ENG]

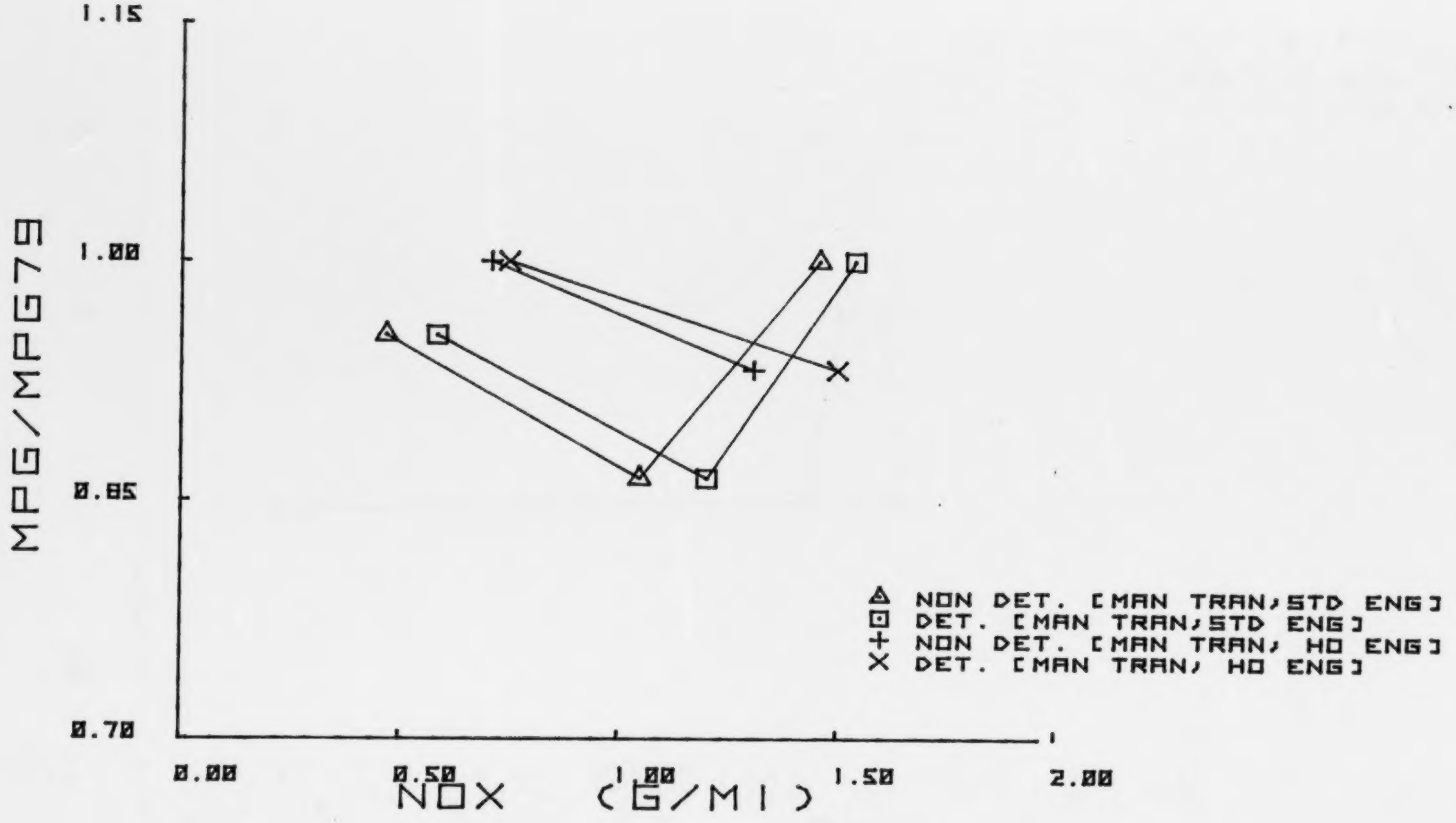

COMBINED MPG VS URBAN CO
GM'S 1.6 LITER ENGINE OVER TIME


COMBINED MPG VS URBAN CO
GM'S 1.6 LITER ENGINE OVER TIME
MPG/MPG79
1.15
1.00
0.85
0.0
2.0
4.0
6.0
8.0
10.0
CO (G/MI)
△ NON DET. [MAN TRAN, HO ENG]
☐ DET. [MAN TRAN, HO ENG]

COMBINED MPG VS. URBAN NOX
GM'S 1.6 LITER ENGINE OVER TIME



COMBINED MPG VS. URBAN NOX
GM'S 1.6 LITER ENGINE OVER TIME



COMBINED MPG VS. HIGHWAY NOX
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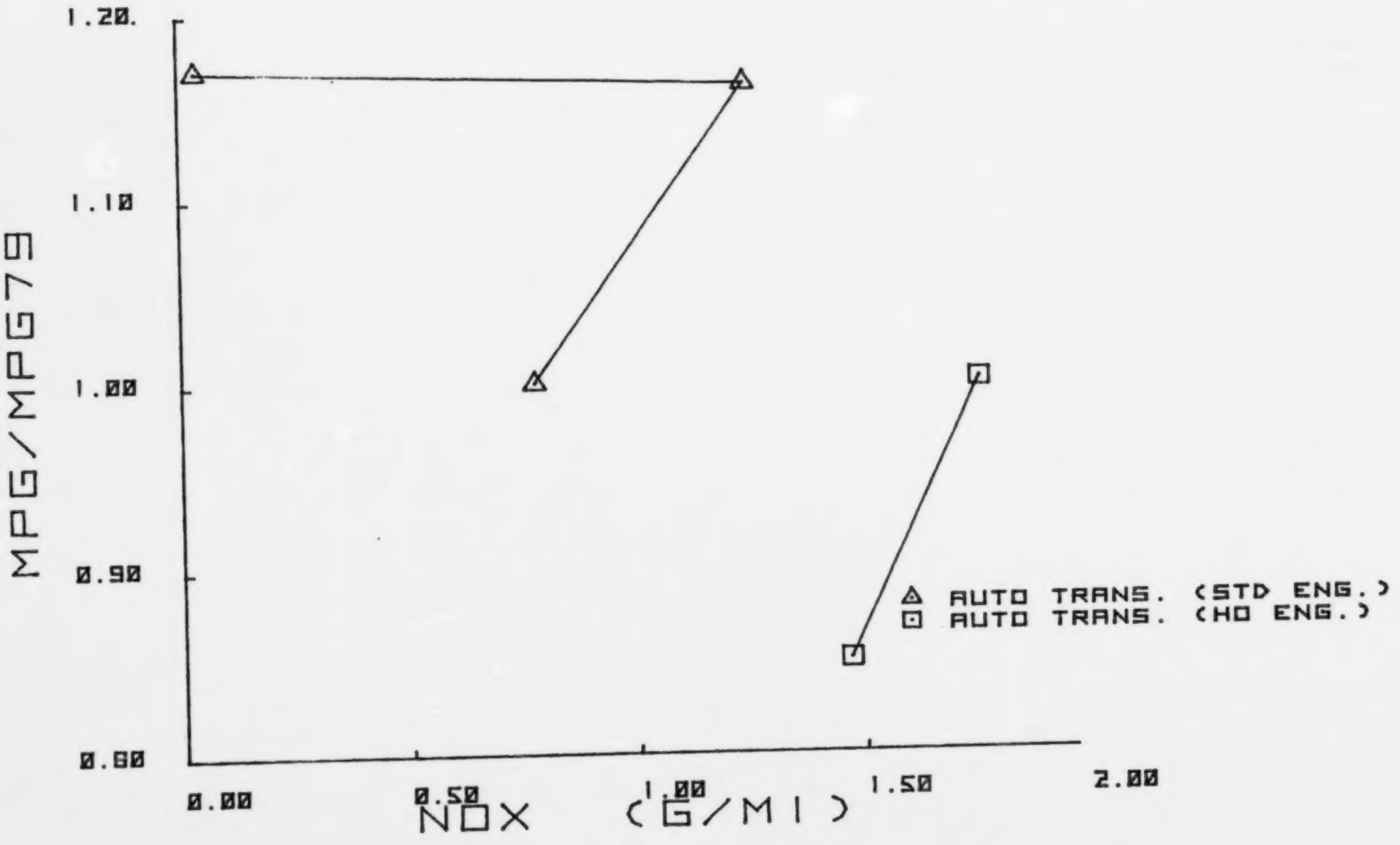
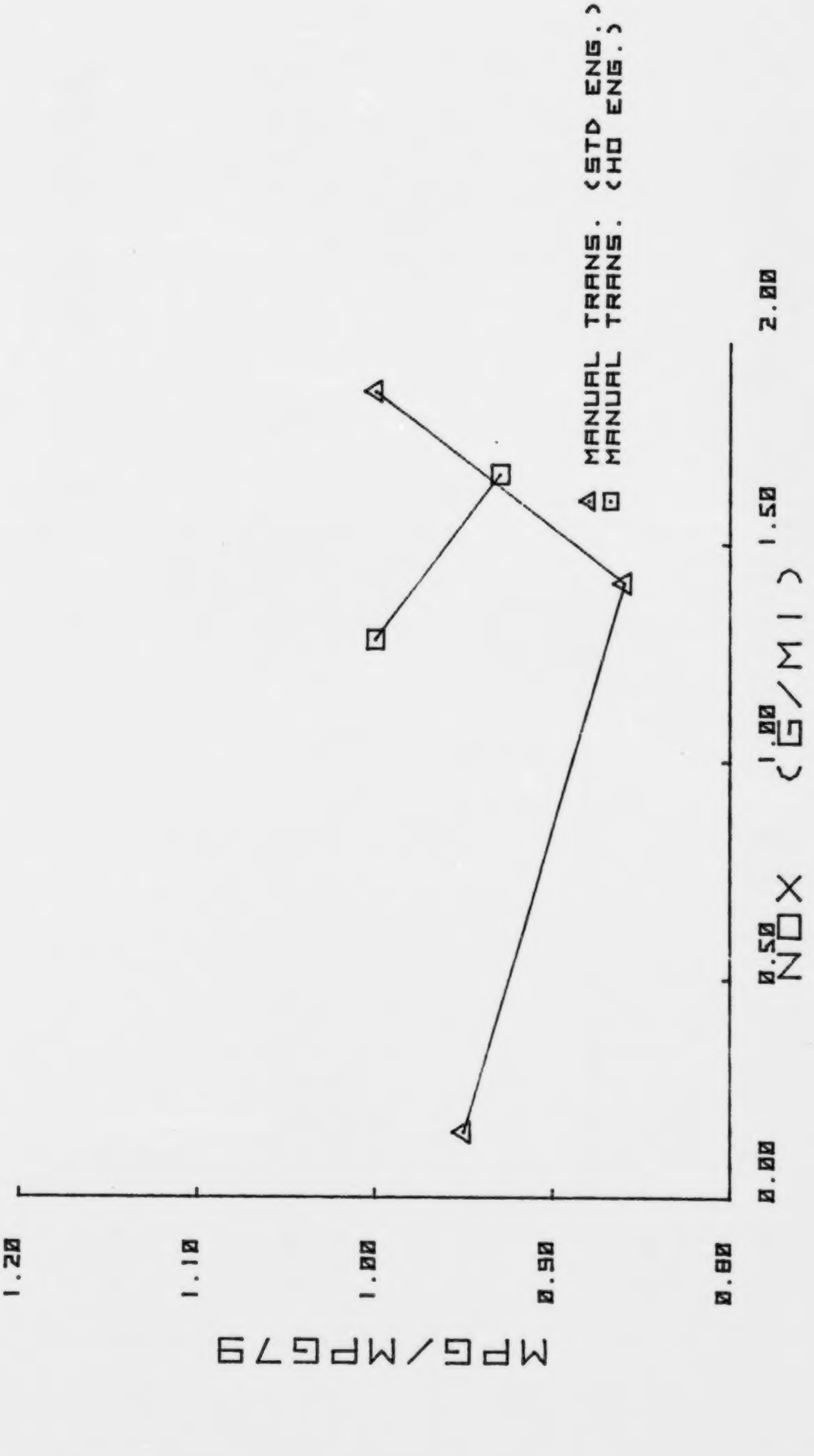
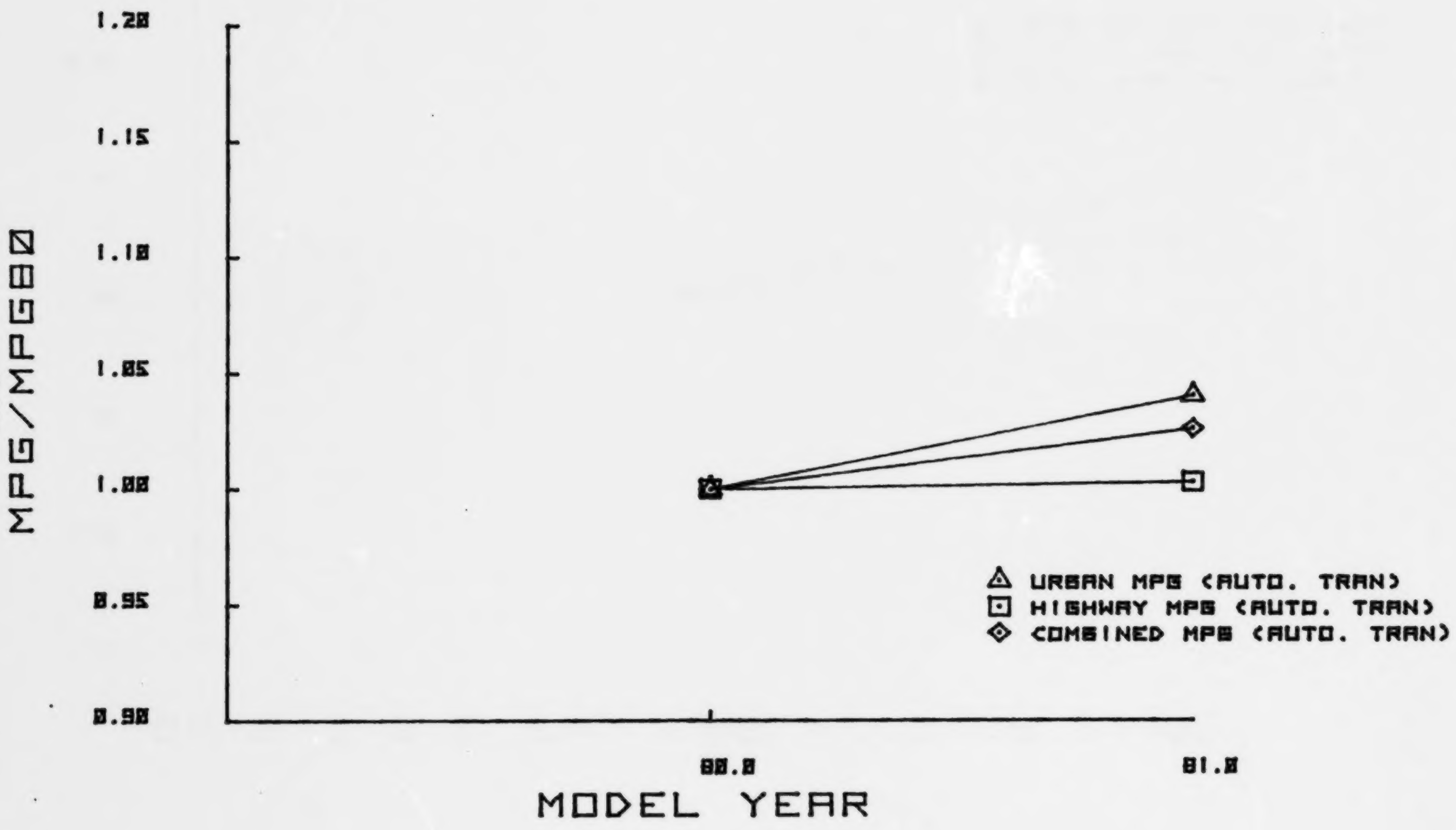


COMBINED MPG VS. HIGHWAY NOX
GM'S 1.6 LITER ENGINE OVER TIME



GM'S 2.5 L FWD ENGINE OVER TIME



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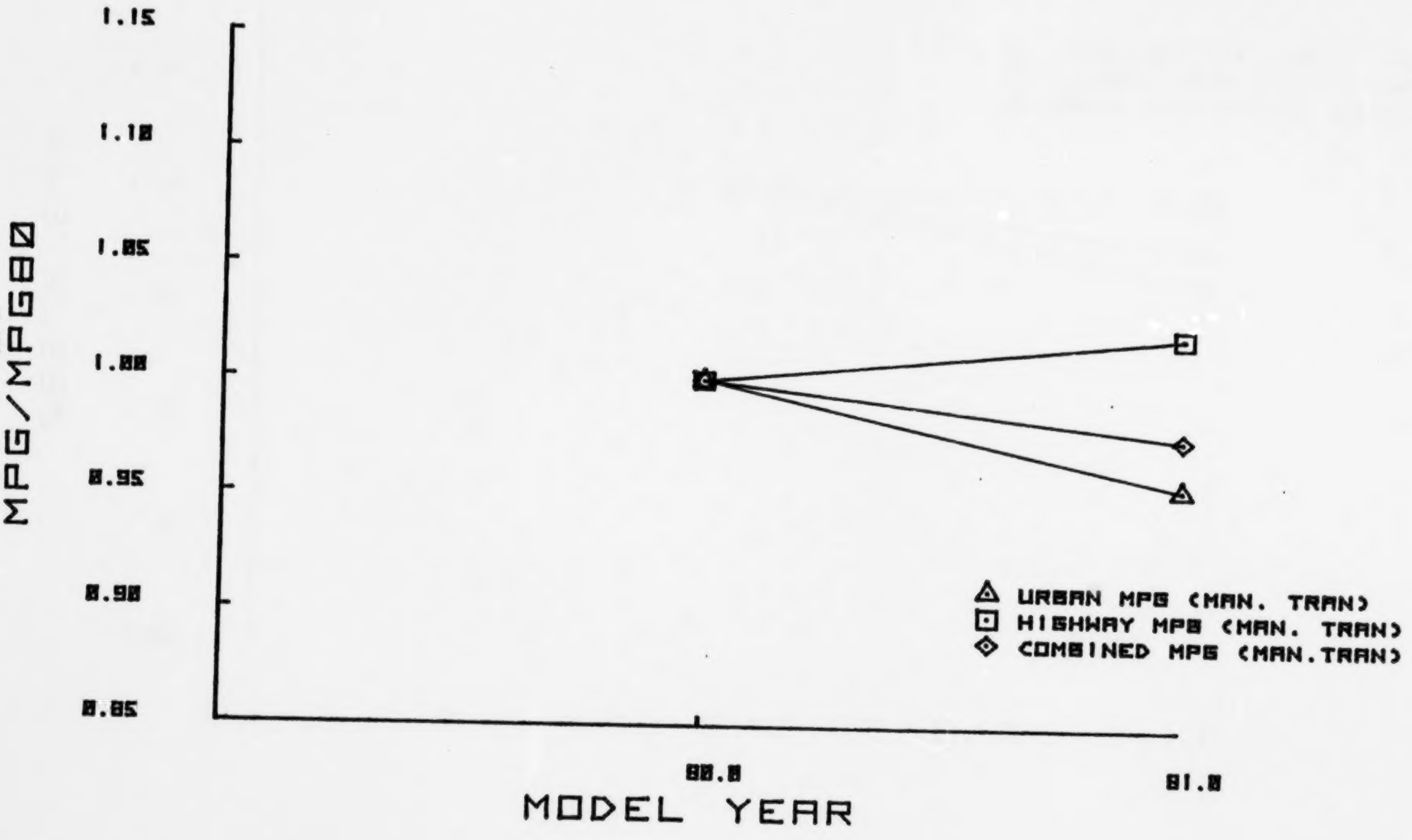
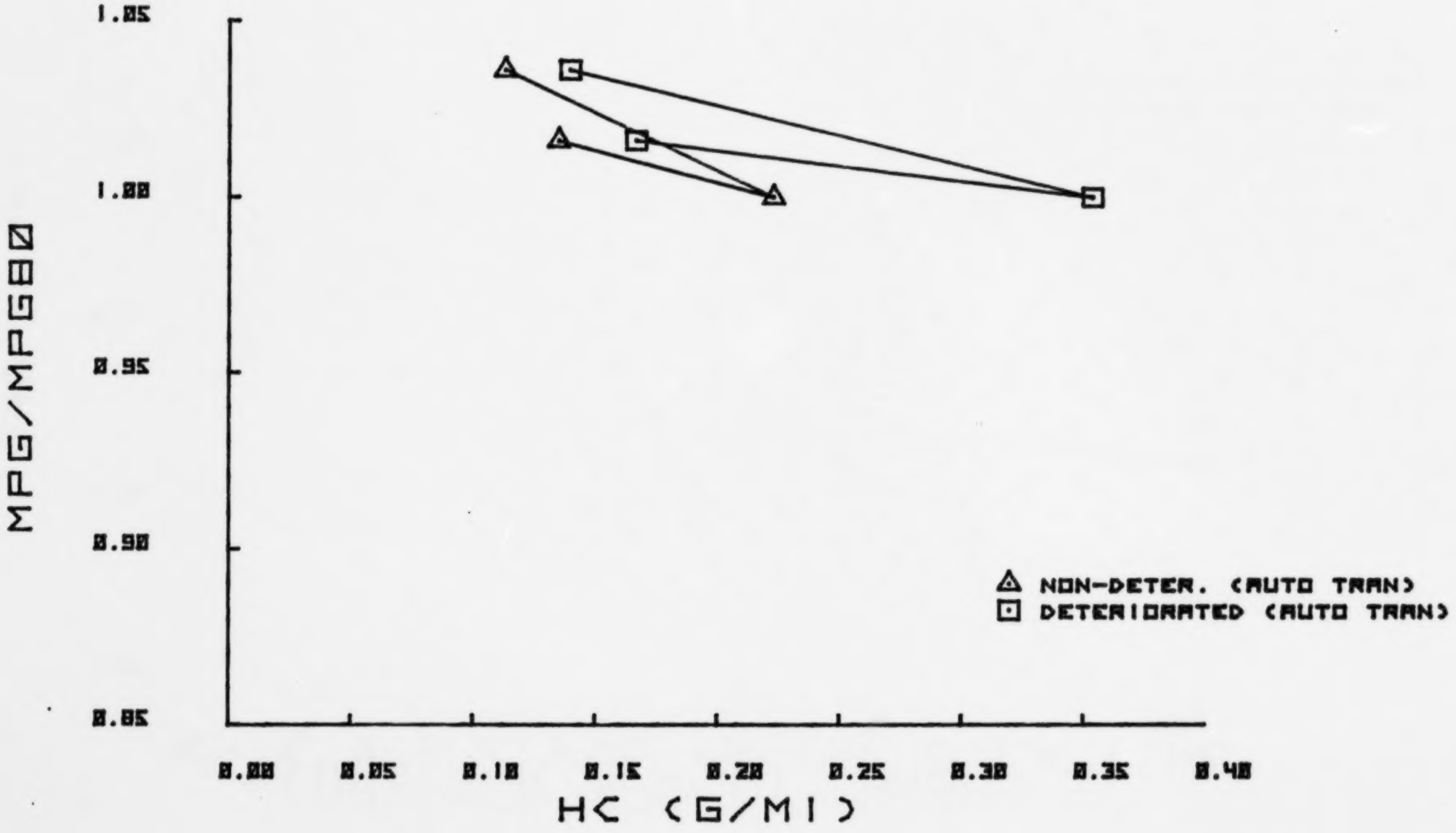
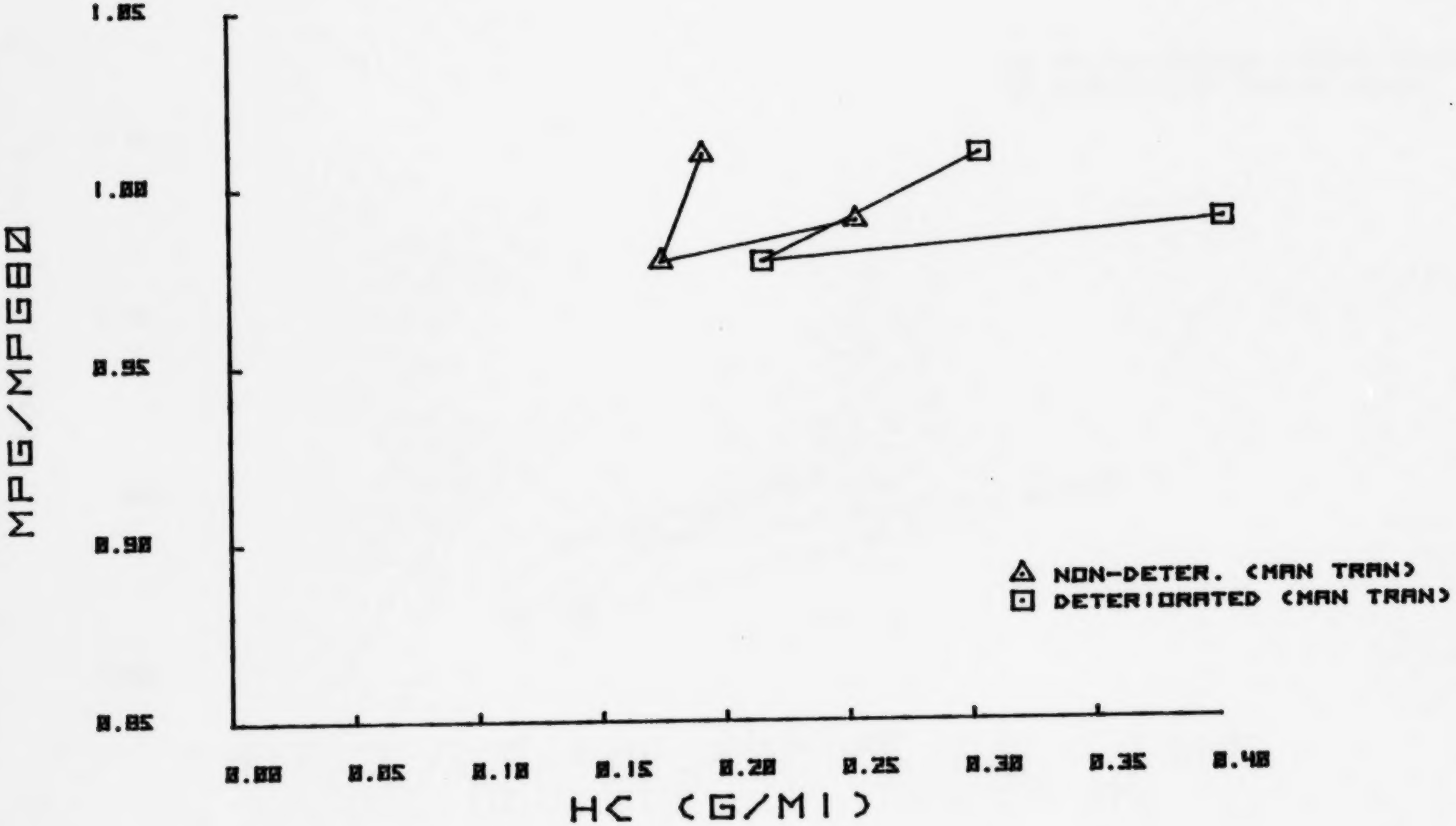


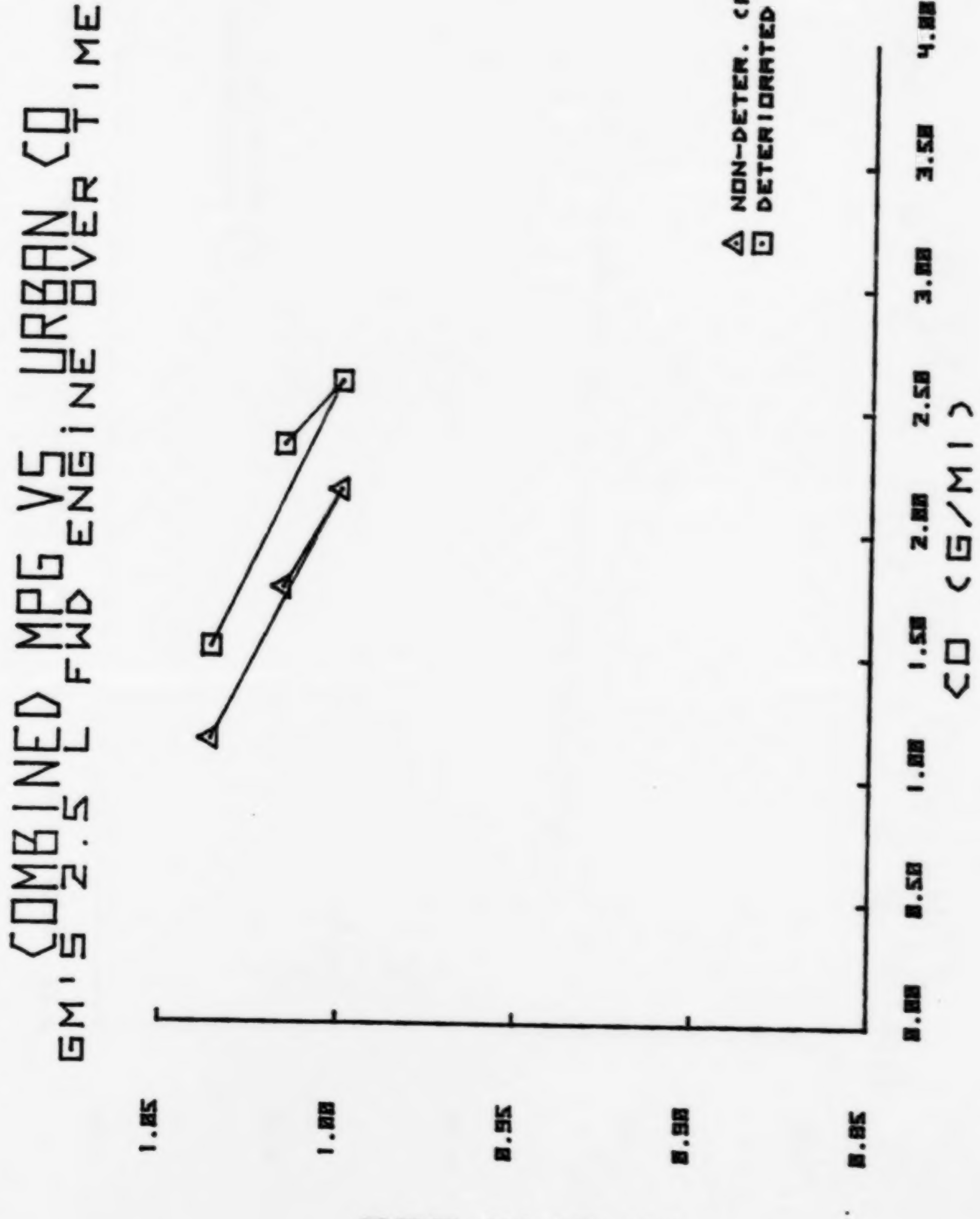
COMBINED MPG VS. URBAN HC

GM'S 2.5 L FWD ENGINE OVER TIME



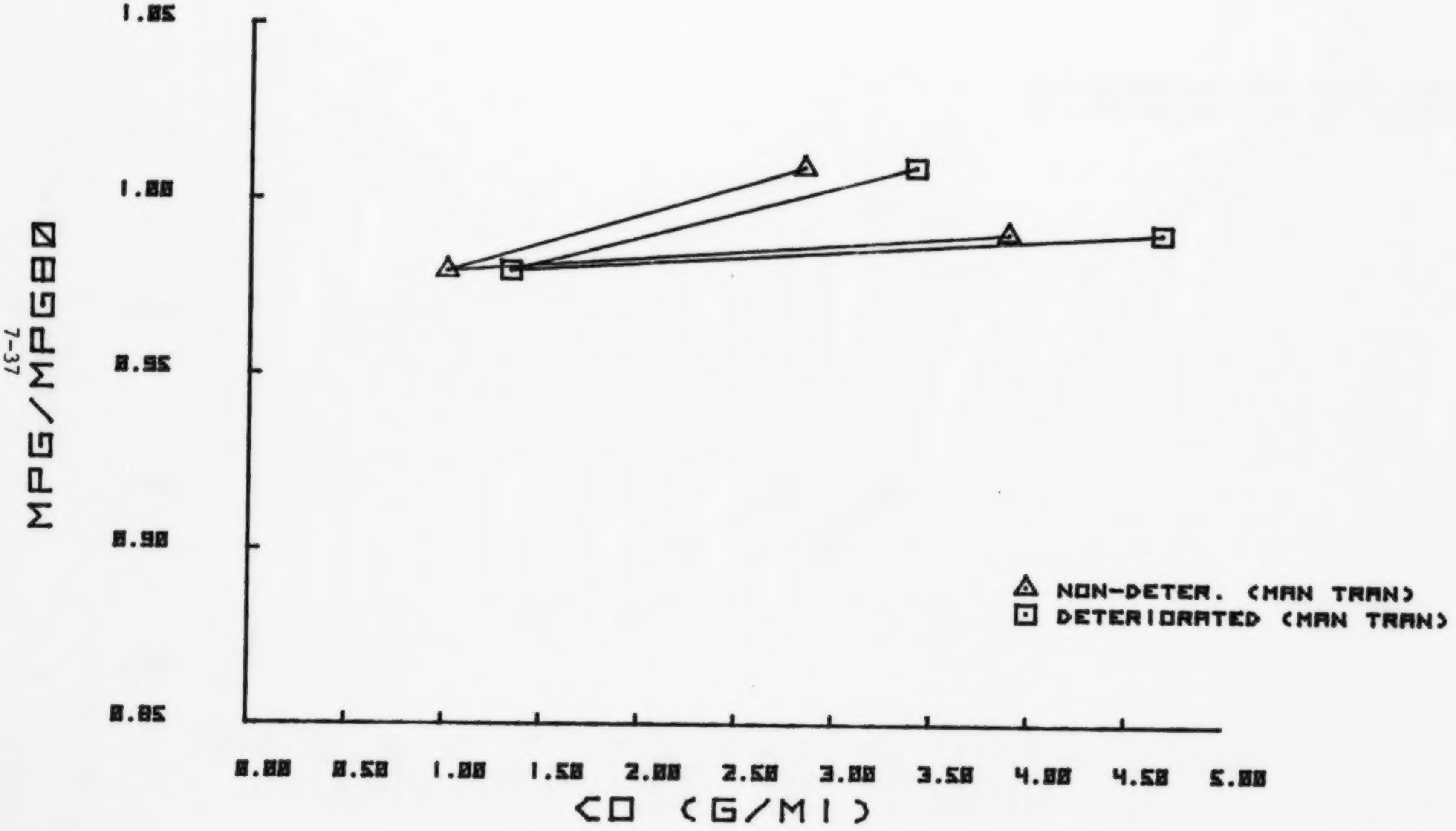
COMBINED MPG VS. URBAN HC
GM'S 2.5 L FWD ENGINE OVER TIME



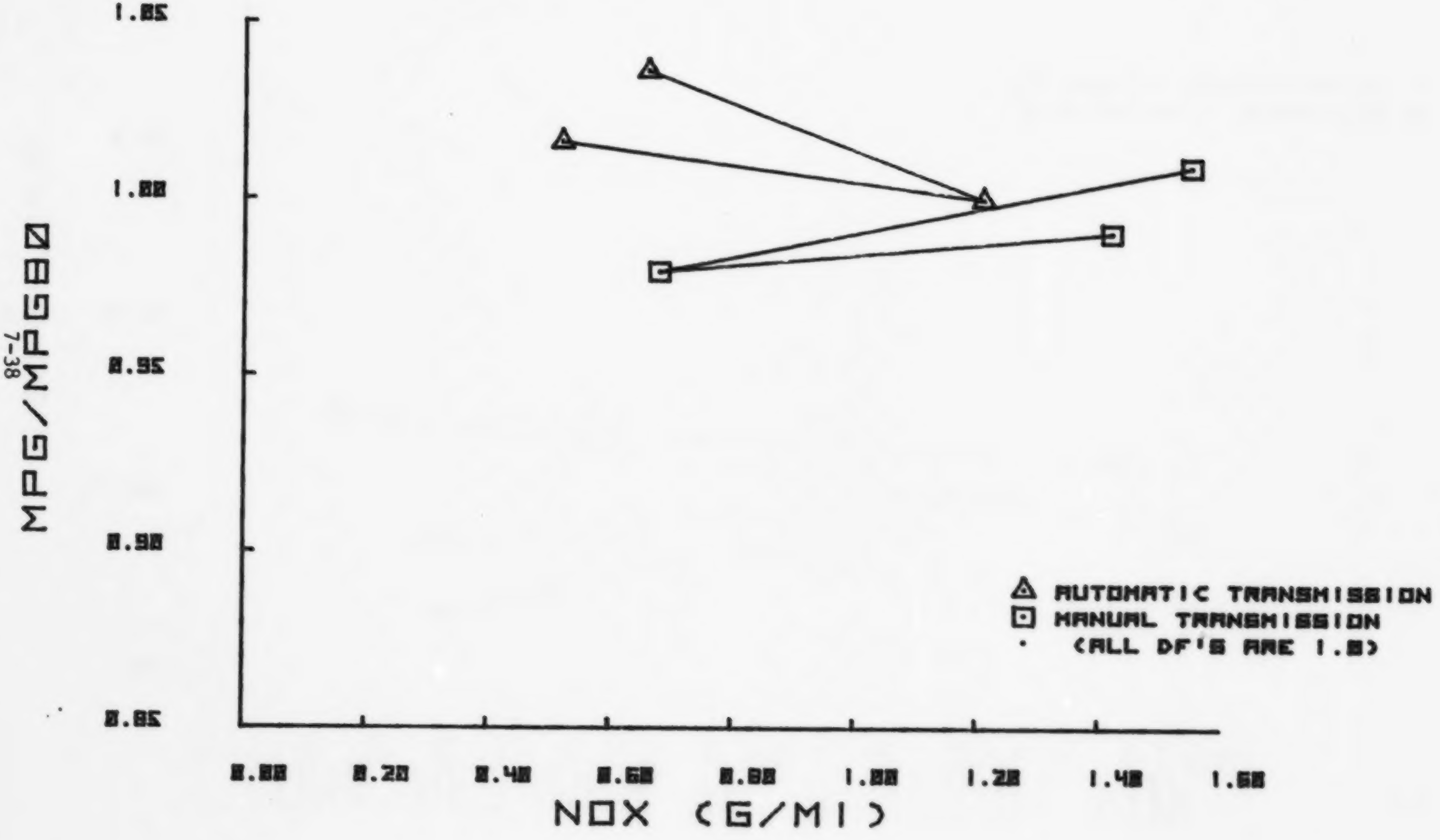


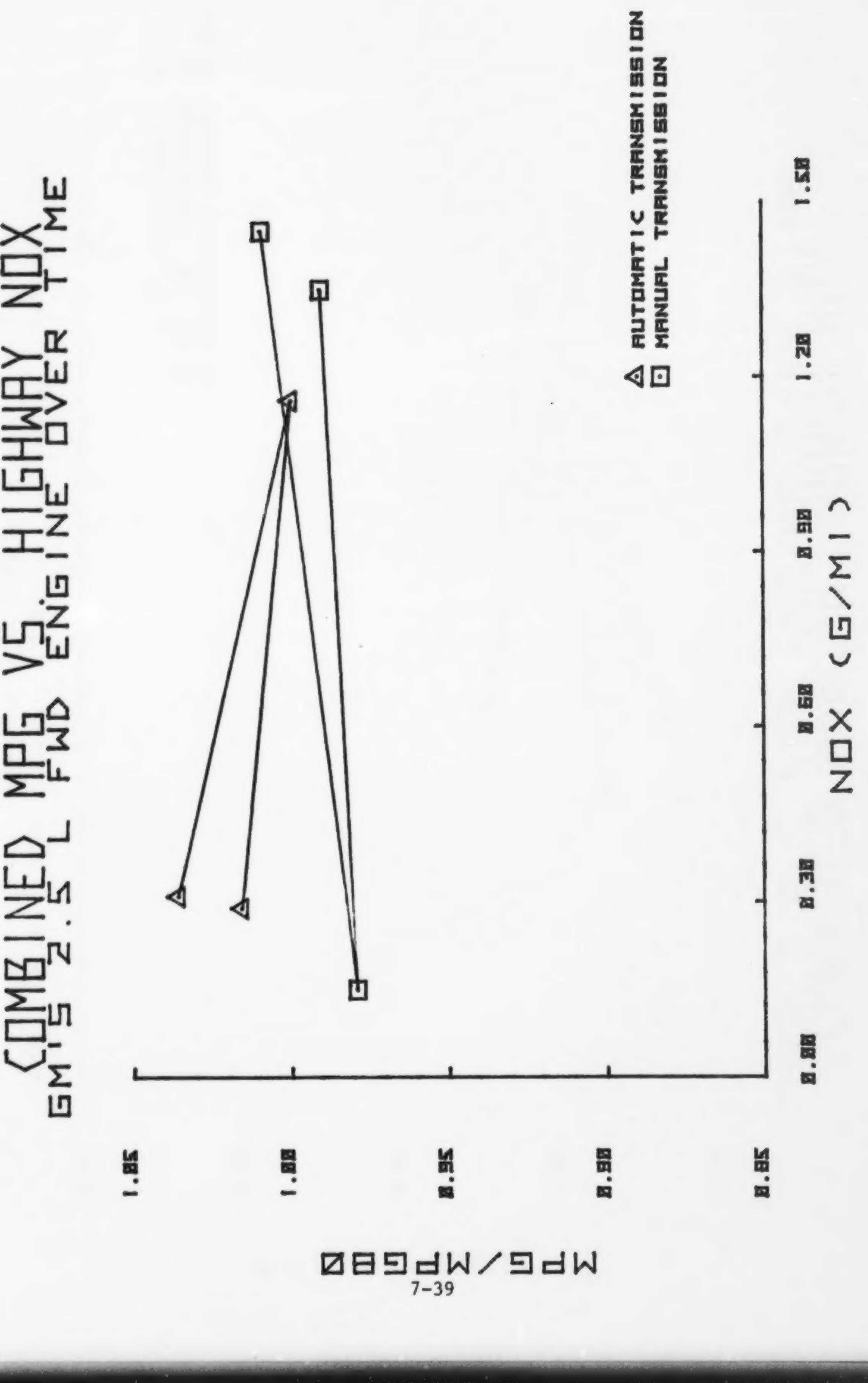
COMBINED MPG VS URBAN CO
GM'S 2.5L FWD ENGINE OVER TIME

COMBINED MPG VS. URBAN CO
GM'S 2.5 L FWD ENGINE OVER TIME

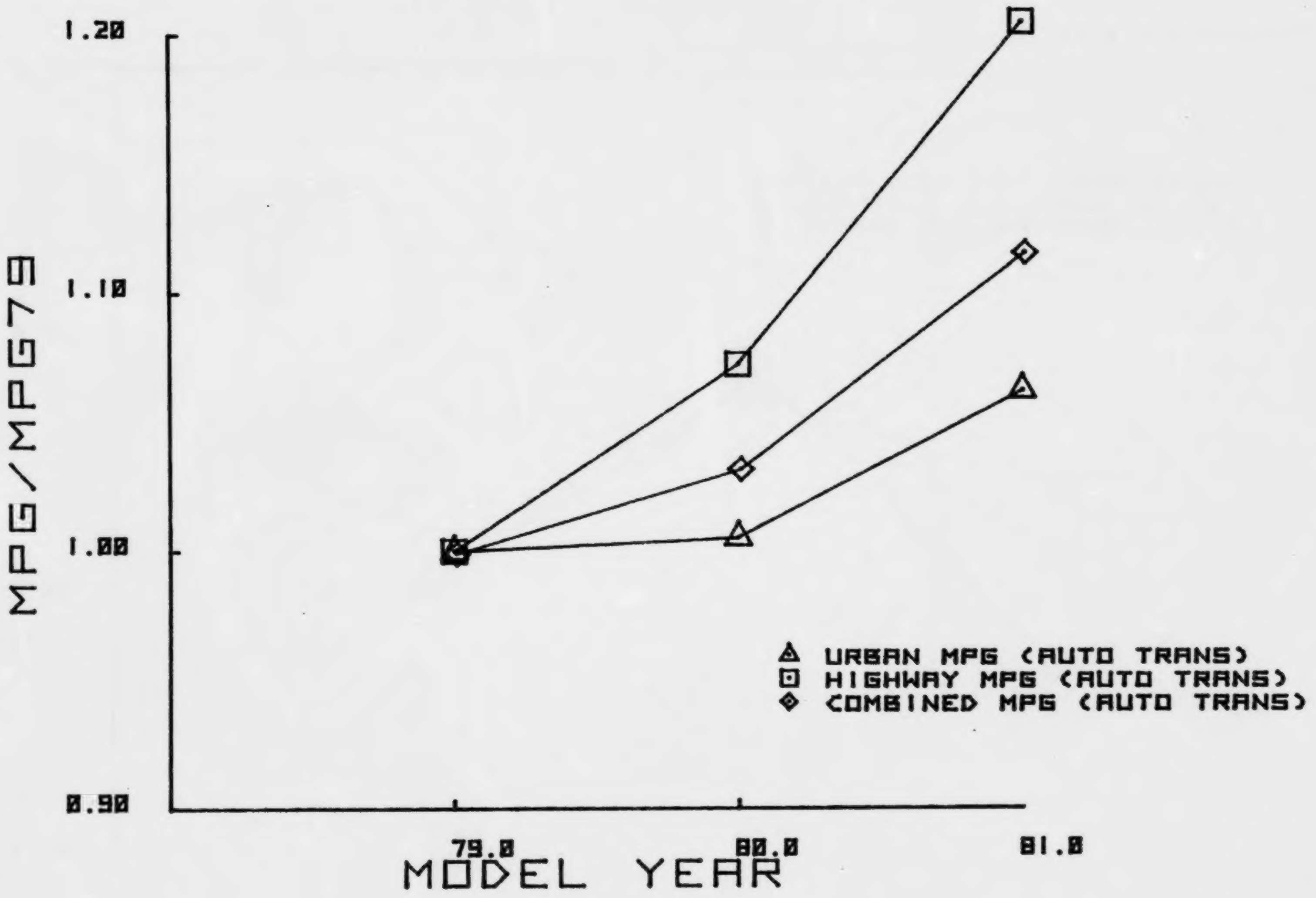


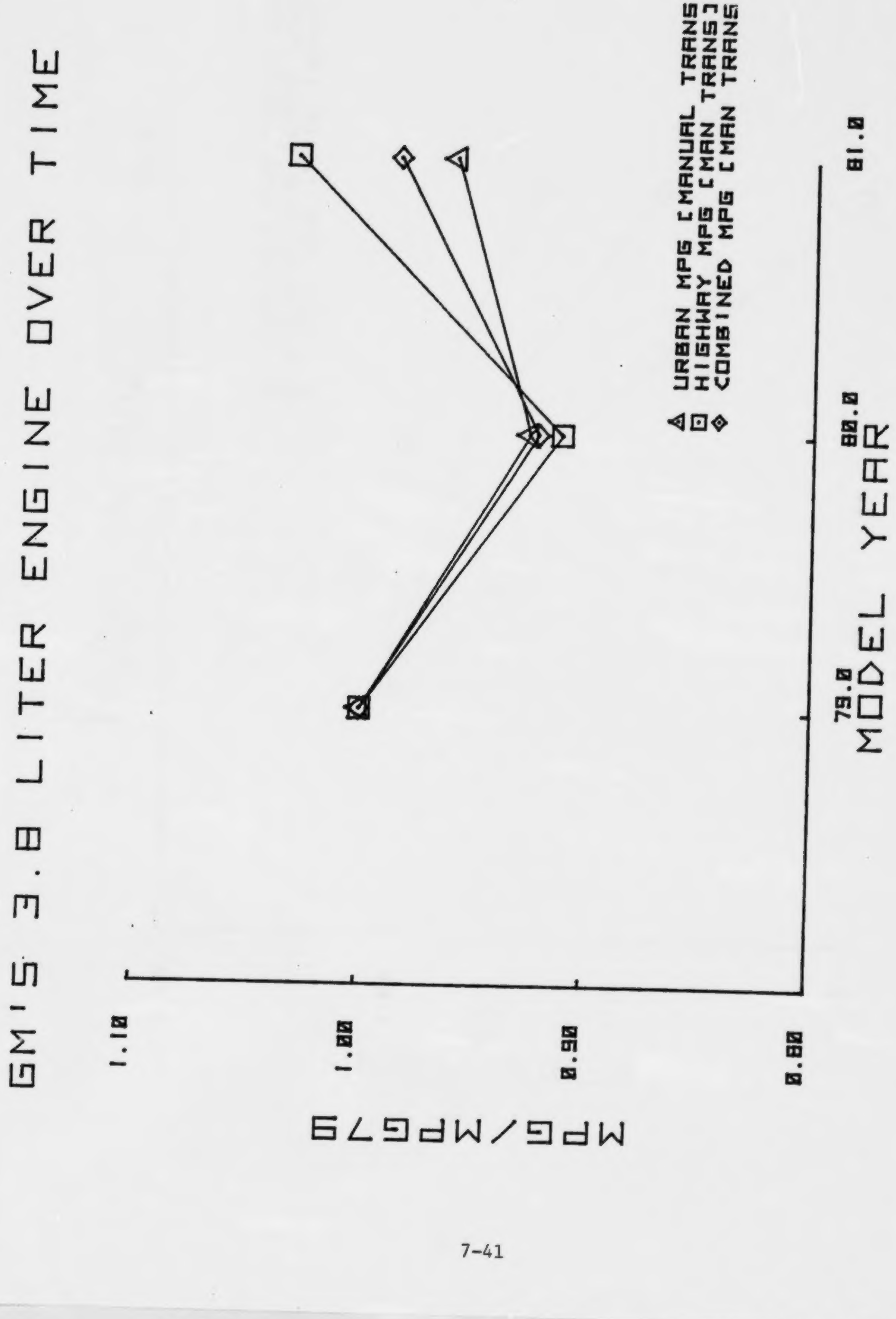
COMBINED MPG VS. URBAN NOX
GM'S 2.5 L FWD ENGINE OVER TIME

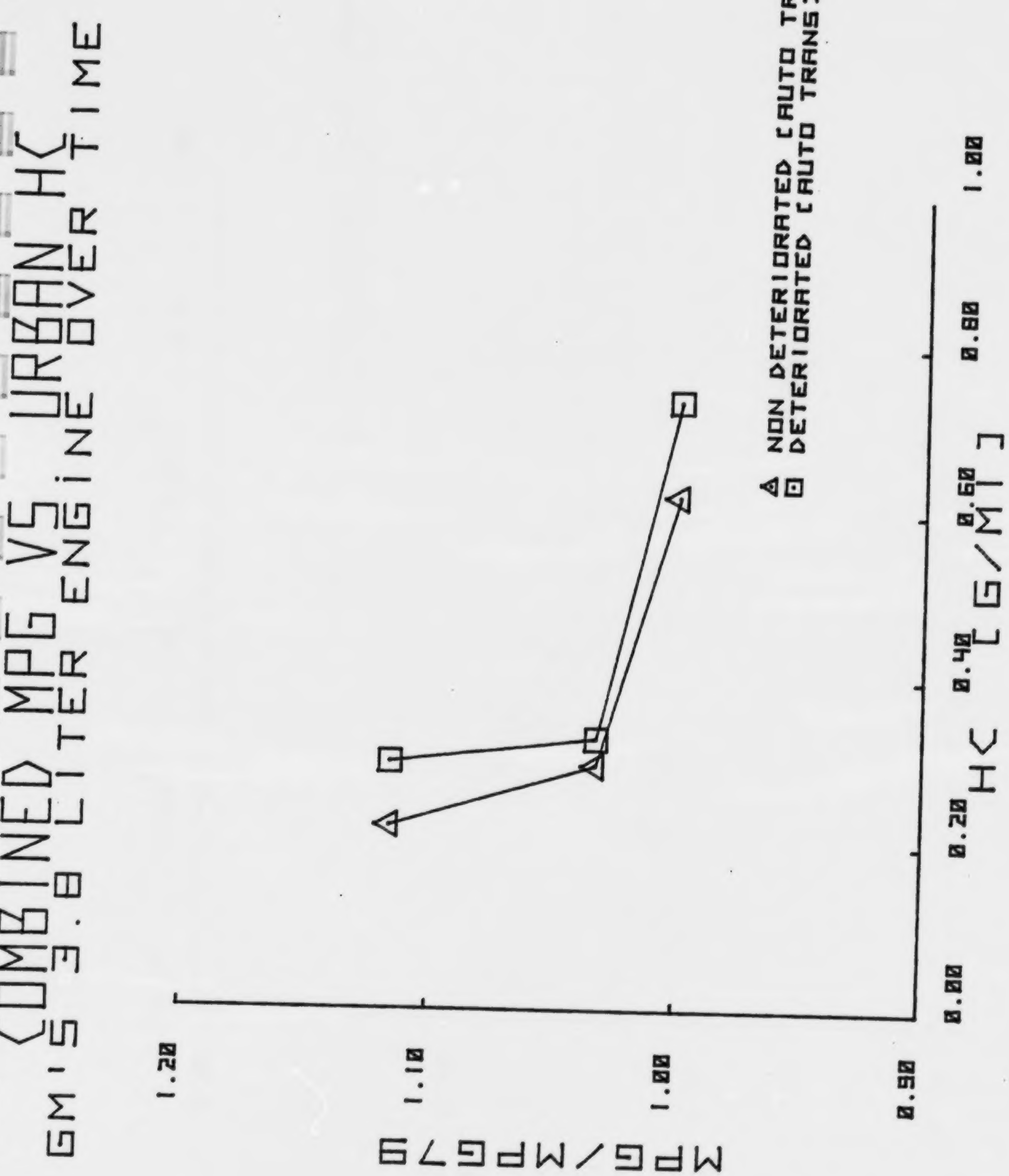



COMBINED MPG VS. HIGHWAY NOX
GM'S 2.5 L FWD ENGINE OVER TIME
MPG/MPG80
1.05
1.00
0.95
0.90
0.85
0.00
0.30
0.60
0.90
1.20
1.50
NOX (G/MI)
△ AUTOMATIC TRANSMISSION
□ MANUAL TRANSMISSION

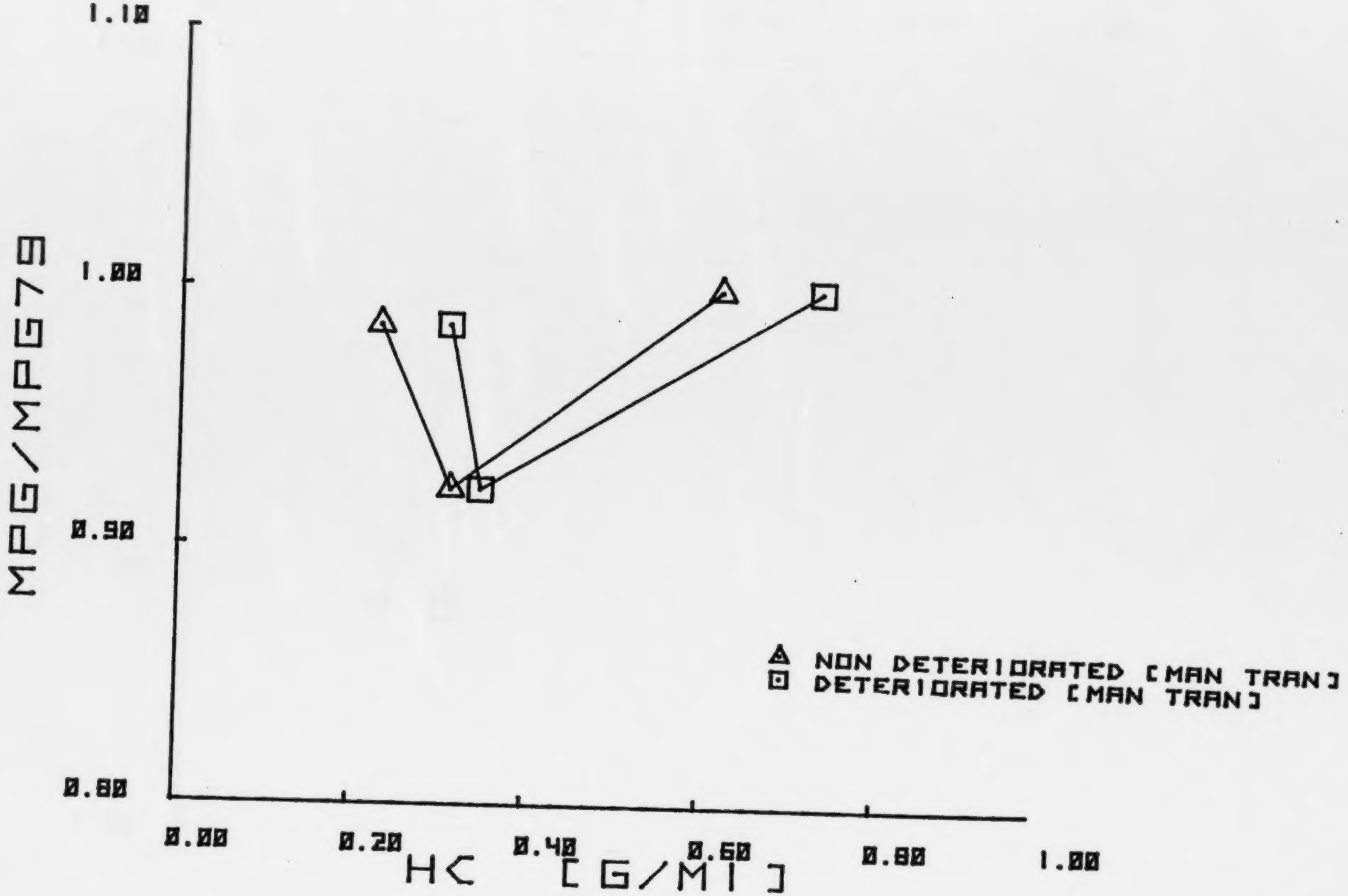
GM'S 3.8 LITER ENGINE OVER TIME



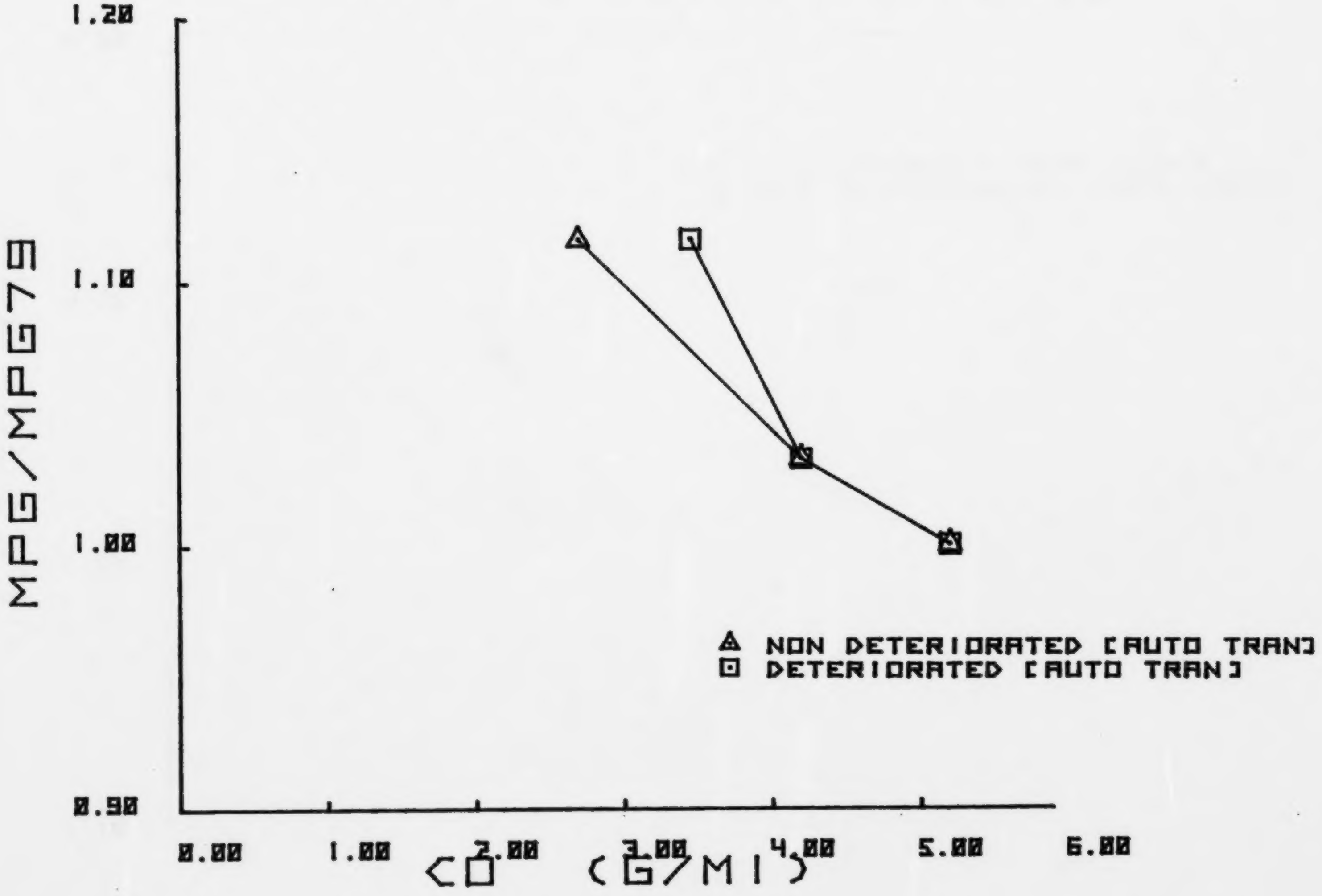

GM'S 3.8 LITER ENGINE OVER TIME
MPG/MPG79
1.10
1.00
0.90
0.80
79.0
80.0
81.0
MODEL YEAR
△ URBAN MPG [MANUAL TRANS]
□ HIGHWAY MPG [MAN TRANS]
◇ COMBINED MPG [MAN TRANS]


COMBINED MPG VS URBAN HC
GM'S 3.8 LITER ENGINE OVER TIME
MPG/MPG79
1.20
1.10
1.00
0.90
0.00
0.20
0.40
0.60
0.80
1.00
HC [G/MI]
△ NON DETERIORATED [AUTO TRANS]
□ DETERIORATED [AUTO TRANS]

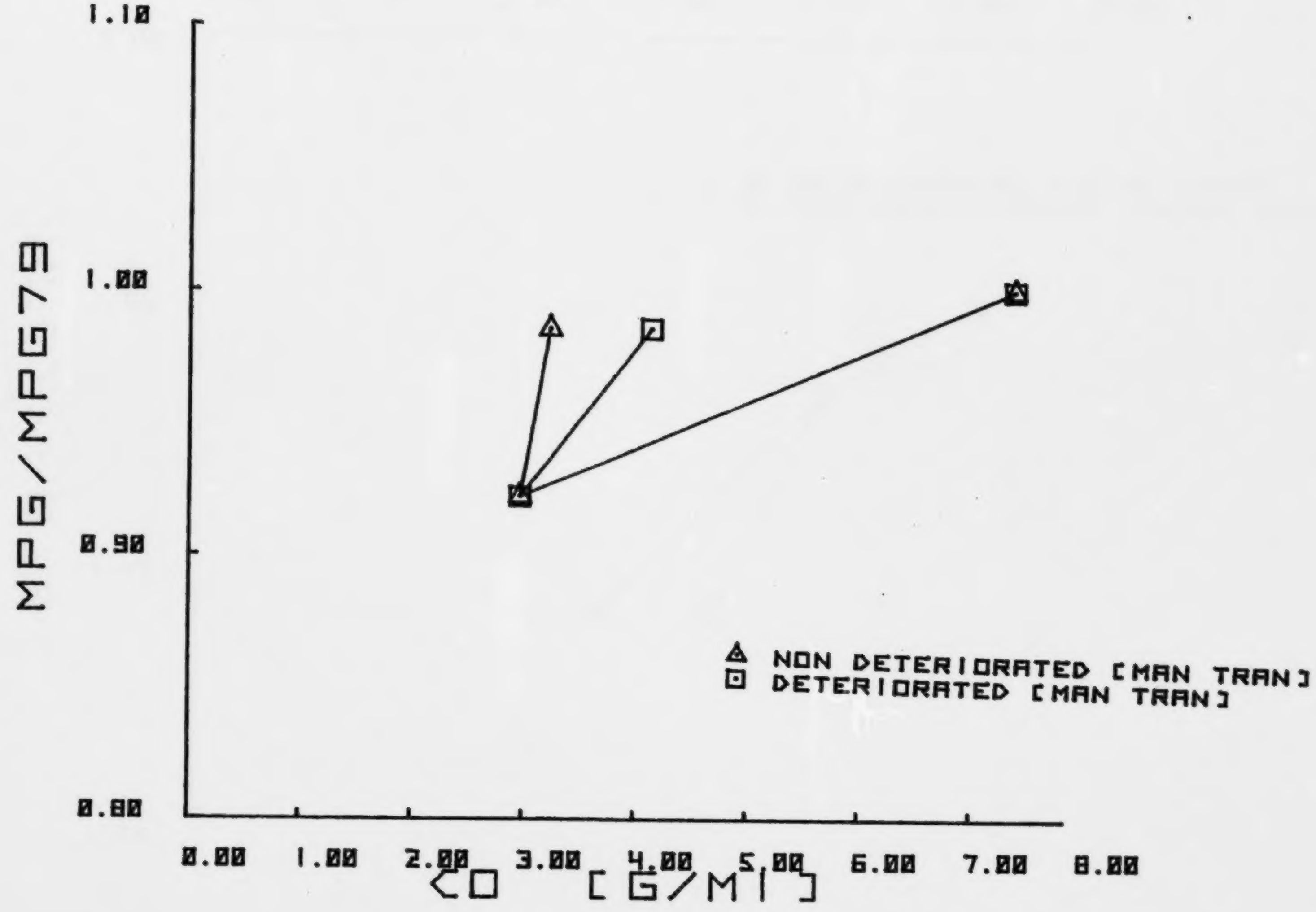
COMBINED MPG VS. URBAN HC
GM'S 3.8 LITER ENGINE OVER TIME



COMBINED MPG VS. URBAN CO
GM'S 3.8 LITER ENGINE OVER TIME



COMBINED MPG VS. URBAN CO
GM'S 3.8 LITER ENGINE OVER TIME



COMBINED MPG VS. URBAN NOX
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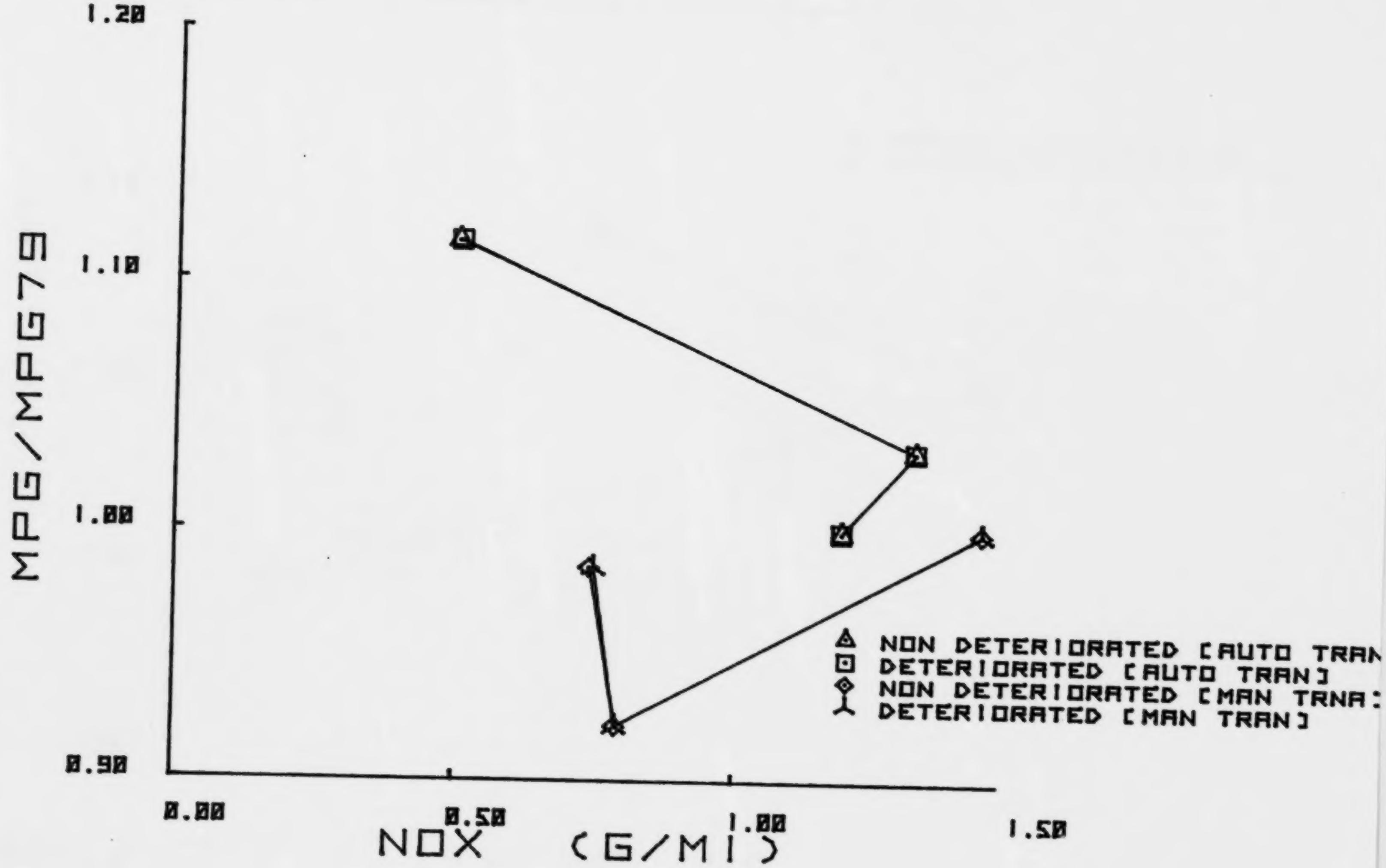
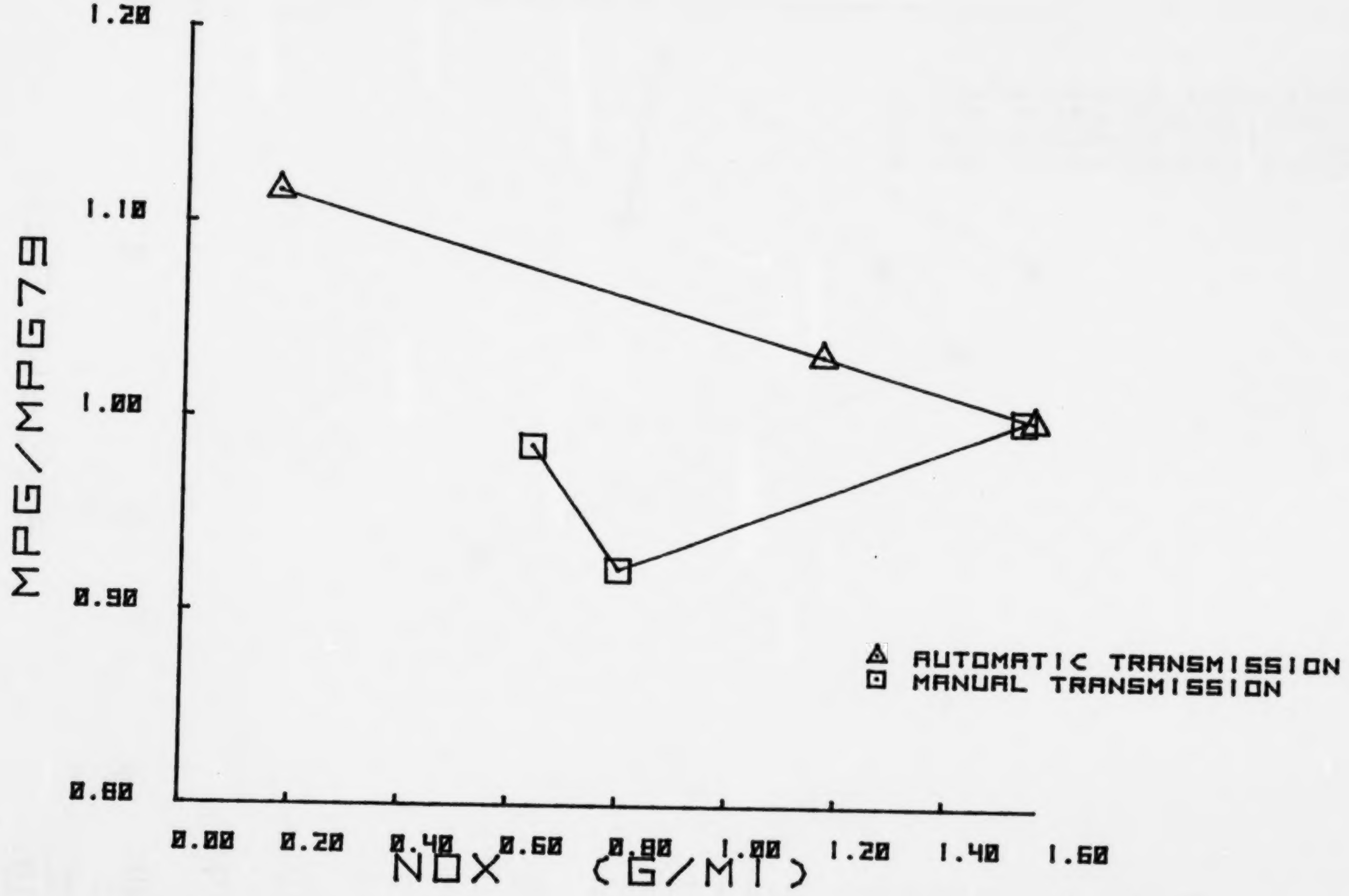


COMBINED MPG VS. HIGHWAY NOX
GM'S 3.8 LITER ENGINE OVER TIME



Appendix 8

Multicollinearity Discussion

Appendix 8 - Multicollinearity Discussion

A. Introduction

This appendix discusses the regression equations presented in Section IV and the impact that multicollinearity had on these equations.

> Interpretation of the multiple regression equation depends implicitly on the assumption that the explanatory variables are not strongly interrelated. It is usual to interpret a regression coefficient as measuring the change in the response variable when the corresponding explanatory variable is increased by one unit and all other explanatory variables are held constant. This interpretation may not be valid if there are strong linear relationships among the explanatory variables. It is always conceptually possible to increase the value of one variable in an estimated regression equation while holding the others constant. However, there may be no information about the result of such a manipulation in the estimation data. Moreover, it may be impossible to change one variable while holding all others constant in the process being studied. When these conditions exist, simple interpretation of the regression coefficient as a marginal effect is lost.
>
> When there is a complete absence of linear relationship among the explanatory variables, they are said to be orthogonal. In most regression applications the explanatory variables are not orthogonal. Usually the lack of orthogonality is not serious enough to affect the analysis. However, in some situations the explanatory variables are so strongly interrelated that the regression results are ambiguous.
>
> The condition of severe nonorthogonality is also referred to as the problem of collinear data, or multicollinearity. It is recommended that one should be extremely cautious about any and all substantive conclusions based on a regression analysis in the presence of multicollinearity.*

In order to address the concerns discussed above, the three regression equations, Cheng, Murrell and Bascunana, (see Section IV. D) were investigated for the presence of multicollinearity.

> Multicollinearity is a question of degree and not of kind. The meaningful distinction is not between the presence and the absence of multicollinearity, but between its various degrees.**

---

* Chatterjee and Price, Regression Analysis By Example, John Wiley & Sons, 1977, pages 143 and 144.

** Jan Kmenta, Elements of Econometrics, Macmillan Publishing Co., 1971, p. 380.

> Given that some multicollinearity almost always exists, the question is, At what point does the degree of multicollinearity cease to be "normal" and become "harmful"? This question has not been satisfactorily resolved. According to one criterion sometimes used in practice, multicollinearity is regarded as harmful if at, say, the 5% level of significance, the value of the F statistic is significantly different from zero but none of the t statistics for the regression coefficients (other than the regression constant) is. In this case we would reject the hypothesis that there is no relationship between Y_i on one side and X_{i2}, $X_{i3}, \ldots, X_{iK}$ on the other side, but we would not reject the hypothesis that any one of the explanatory variables is irrelevant in influencing Y_i. Such a situation indicates that the separate influence of each of the explanatory variables is weak relative to their joint influence on Y_i. This is symptomatic of a high degree of multicollinearity, which prevents us from disentangling the separate influences of the explanatory variables*.

The objectivity of this test makes it a desirable method for the detection of multicollinearity, but as Kmenta alluded to in his following statement, there are other harmful effects caused by multicollinearity which may be present, but not brought to light by the use of this method.

> The disadvantage of this criterion is that it is too strong in the sense that multicollinearity is considered as harmful only when all of the influences of the explanatory variables on Y cannot be disentangled.*

With respect to the detection of multicollinearity, Chatterjee and Price stated** the following:

> Multicollinearity is associated with unstable estimated regression coefficients. This situation results from the presence of strong linear relationships among the explanatory variables. It is not a problem of misspecification. Therefore, the empirical investigation of problems that result from a collinear data set should begin only after the model has been satisfactorily specified. However, there may be some indications of multicollinearity that are encountered during the process of adding, deleting, and transforming variables or data points in search of the good model. Indications of multicollinearity that appear as instability in the estimated coefficients are as follows:

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* Kmenta, op. cit., p 390.

** Chatterjee and Price, op. cit., p. 155-156.

1. large changes in the estimated coefficients when a variable is added or deleted,

2. large changes in the coefficients when a data point is altered or droppped.

Once the residual plots indicate that the model has been satisfactorily specified, multicollinearity may be present if

3. the algebraic signs of the estimated coefficients do not conform to prior expectations or

4. coefficients of variables that are expected to be important have large standard errors.

The presence of multicollinearity is also indicated by the size of the correlation coefficients that exist among the explanatory variables. A large correlation between a pair of explanatory variables indicates a strong linear relationship between those two variables. [A table of correlation coefficients (r) will be referred to as a correlation matrix.]

The source of multicollinearity may be more subtle than a simple relationship between two variables. A linear relation can involve many of the explanatory variables. It may not be possible to detect such a relationship with a simple correlation coefficient.

B. Discussion

I. Cheng Equation

$$MPG = A(ETW^{-1}) + B(VDHP) + C(DISP) + D(RTHP) + E(N/V) + F$$

	urban	highway	composite
A =	70,077	80,599	77,444
B =	0.2908	-0.4058	0.0458
C =	-0.0044	-0.0301	-0.0084
D =	-0.0291	-0.0271	-0.0366
E =	-0.1047	-0.4356	-0.2187
F =	4.0439	34.546	13.560

1. The following observations, with respect to urban fuel economy, suggest that multicollinearity is present:

a. The positive sign for coefficient B for urban and composite fuel economy is counter-intuitive. It means that for this equation, urban and composite fuel economy increase as dynamometer horsepower increases.

b. Displacement (DISP) was expected to be an important variable for its effect on fuel economy, yet for this equation it was not statistically significant for predicting urban fuel economy at a 90% confidence level. Its partial correlation (r) was only -0.077 (r^2 = .006); in other words, it only explained 0.6% of the variation in fuel economy (see tables 8-1 to 8-3). The t-statistic for displacement was -1.5562 with an attained significance of 0.1204. When a variable which was expected to be important is found to not be statistically significant, the cause of the paradox could be multicollinearity.

c. The correlation coefficients (r) for the variables (see table 8-1) are as high as 0.89. This indicates that there is a high degree of correlation between some of the explanatory variables.

d. The standard error for displacement (.0028), relative to the magnitude of the coefficient, is large.

2. Conclusion: Multicollinearity is present in the Cheng equation used to predict urban fuel economy. There is probably multicollinearity in the other two versions also. This would tend to imply caution in the use the equation, but since the equation was (1) used for a residual analysis and (2) used on the same data from which it was generated, the appropriate caution in the use of the equation has been employed.

Table 8-1

Correlation Matrix for the Cheng Variables - FTP Data

Variable	UMPG	1/ETW	VDHP	DISP	RTHP	CMPR	AXLR	N/V	FTPHC	FTPCO	FTPNOX	FEHC	FECO	FENOX
UMPG	1.00													
1/ETW	.93	1.00												
VDHP	-.57	-.66	1.00											
DISP	-.82	-.89	.59	1.00										
RTHP	-.85	-.84	.49	.84	1.00									
CMPR	.45	.47	-.21	-.50	-.47	1.00								
AXLR	.49	.62	-.25	-.69	-.47	.38	1.00							
N/V	.59	.73	-.42	-.78	-.61	.38	.71	1.00						
FTPHC	-.27	-.29	.13	.27	.30	-.06	-.25	-.28	1.00					
FTPCO	-.17	-.13	.01	.09	.11	-.07	-.15	-.09	.51	1.00				
FTPNOX	-.04	-.12	.04	.23	.04	-.10	-.32	-.22	.15	.12	1.00			
FEHC	-.21	-.18	.16	.15	.23	-.05	-.10	-.10	.26	.18	-.17	1.00		
FECO	-.13	-.08	.11	.01	.09	.02	.05	.04	.04	.28	-.22	.63	1.00	
FENOX	.07	.02	.02	.11	-.06	-.01	-.19	-.11	.14	-.01	.73	-.16	-.28	1.00

Table 8-2

Correlation Matrix for the Cheng Variables - HFET Data

	HMPG	1/ETW	VDHP	DISP	RTHP	CMPR	AXLR	N/V	FTPHC	FTPCO	FTPNOX	FEHC	FECO	FENOX
HMPG	1.00													
1/ETW	.86	1.00												
VDHP	-.65	-.66	1.00											
DISP	-.77	-.89	.59	1.00										
RTHP	-.78	-.84	.49	.84	1.00									
CMPR	.42	.47	-.21	-.50	-.47	1.00								
AXLR	.42	.62	-.25	-.69	-.47	.38	1.00							
N/V	.42	.73	-.42	-.78	-.61	.38	.71	1.00						
FTPHC	-.18	-.29	.13	.27	.30	-.06	-.25	-.28	1.00					
FTPCO	-.13	-.13	.01	.09	.11	-.07	-.15	-.09	.51	1.00				
FTPNOX	-.02	-.12	.04	.23	.04	-.10	-.32	-.22	.15	.12	1.00			
FEHC	-.20	-.18	.16	.15	.23	-.05	-.10	-.10	.26	.18	-.17	1.00		
FECO	-.14	-.08	.11	.01	.09	.02	.05	.04	.04	.28	-.22	.63	1.00	
FENOX	.08	.02	.02	.11	-.06	-.01	-.19	-.11	.14	-.01	.73	-.16	-.28	1.00

Table 8-3

Correlation Matrix for the Cheng Variables - Composite Data

	CMPG	1/ETW	VDHP	DISP	RTHP	CMPR	AXLR	N/V	FTPHC	FTPCO	FTPNOX	FEHC	FECO	FENOX
CMPG	1.00													
1/ETW	.92	1.00												
VDHP	-.61	-.66	1.00											
DISP	-.82	-.89	.59	1.00										
RTHP	-.84	-.84	.49	.84	1.00									
CMPR	.45	.47	-.21	-.50	-.47	1.00								
AXLR	.47	.62	-.25	-.69	-.47	.38	1.00							
N/V	.54	.73	-.42	-.78	-.61	.38	.71	1.00						
FTPHC	-.24	-.29	.13	.27	.30	-.06	-.25	-.28	1.00					
FTPCO	-.16	-.13	.01	.09	.11	-.07	-.15	-.09	.51	1.00				
FTPNOX	-.03	-.12	.04	.23	.04	-.10	-.32	-.22	.15	.12	1.00			
FEHC	-.21	-.18	.16	.15	.23	-.05	-.10	-.10	.26	.18	-.17	1.00		
FECO	-.14	-.08	.11	.01	.09	.02	.05	.04	.04	.28	-.22	.63	1.00	
FENOX	.07	.02	.02	.11	-.06	-.01	-.19	-.11	.14	-.01	.73	-.16	-.28	1.00

II. Murrell Equation

$$\begin{aligned} MPG = {} & A(CID \times N/V)^{-0.8} + B\,(ETW)^{-0.67} \\ & + C(RTHP/ETW) + D(RTHP/CID) \\ & + E[(CMPR^{0.4} - 1)/CMPR^{0.4}] + F \end{aligned}$$

Coeff.	urban	highway	composite
A =	7501	29,378	14,989
B =	5764	3,956	5602
C =	-47.36	227.2	36.28
D =	-5.025	-16.80	-10.09
E =	16.20	-1.843	-1.700
F =	-17.03	-10.69	-8.915

Tables 8-4, 8-5, and 8-6 show the correlation matrices for this equation. Multicollinearity probably exists.

III. Bascunana Equation

$$MPG = A[\,(ETW)^{a}\,(DISP)^{b}\,(N/V)^{c}\,]$$

Coeff.	urban	highway	composite
A =	141,482	959,401	436,918
a =	-0.8659	-0.7840	-0.8831
b =	-0.1889	-0.3301	-0.2323
c =	-0.2403	-0.6450	-0.4086

Tables 8-7, 8-8, and 8-9 show the correlation matrices. Multicollinearity is present.

Table 8-4

Correlation Matrix for the Murrell Variables - FTP Data

Variable	$UMPG$	$ETW^{-.67}$	$\frac{RTHP}{ETW}$	$\frac{RTHP}{CID}$	$\frac{CR^{.4}-1}{CR^{.4}}$	$\left(\frac{CID}{N/V}\right)^{-.8}$
$UMPG$	1.00					
$ETW^{-0.67}$	.93	1.00				
$\frac{RTHP}{ETW}$	-.41	-.28	1.00			
$\frac{RTHP}{CID}$	.45	.58	.32	1.00		
$\frac{CR^{.4} - 1}{CR^{.4}}$	.47	.46	-.23	.28	1.00	
$\left(\frac{CID}{N/V}\right)^{-.8}$	.87	.87	-.33	.62	.45	1.00

Table 8-5

Correlation Matrix for the Murrell Variables - HFET Data

Variable						
HMPG	1.00					
$ETW^{-0.67}$	.86	1.00				
$\frac{RTHP}{ETW}$	-.37	-.30	1.00			
$\frac{RTHP}{CID}$	.42	.57	.29	1.00		
$\frac{CR^{.4} - 1}{CR^{.4}}$	.42	.48	-.28	.26	1.00	
$\left(\frac{CID}{N/V}\right)^{-.8}$	.90	.87	-.38	.60	.45	1.00
	HMPG	$ETW^{-.67}$	$\frac{RTHP}{ETW}$	$\frac{RTHP}{CID}$	$\frac{CR^{.4} -1}{CR^{.4}}$	$\left(\frac{CID}{N/V}\right)^{-.8}$

Table 8-6

Correlation Matrix for the Murrell Variables - Composite Data

Variable						
CMPG	1.00					
$ETW^{-0.67}$	.91	1.00				
$\frac{RTHP}{ETW}$	-.46	-.33	1.00			
$\frac{RTHP}{CID}$	.40	.55	.28	1.00		
$\frac{CR^{.4} - 1}{CR^{.4}}$	.44	.47	-.26	.30	1.00	
$\frac{CID}{N/V}^{-.8}$	.89	.86	-.41	.58	.46	1.00
	CMPG	$ETW^{-.67}$	$\frac{RTHP}{ETW}$	$\frac{RTHP}{CID}$	$\frac{CR^{.4} -1}{CR^{.4}}$	$\left(\frac{CID}{N/V}\right)^{-.8}$

Table 8-7

Correlation Matrix for the Bascunana Variables - FTP Data

Variable	UMPG	ETW[a]	DISP[b]	(N/V)[c]
UMPG	1.00			
ETW[a]	-.94	1.00		
DISP[b]	-.90	.96	1.00	
(N/V)[c]	.65	-.75	-.82	1.00

Table 8-8

Correlation Matrix for the Bascunana Variables - HFET Data

Variable	HMPG	ETW[a]	DISP[b]	(N/V)[c]
HMPG	1.00			
ETW[a]	-.87	1.00		
DISP[b]	-.83	.94	1.00	
(N/V)[c]	.47	-.75	-.82	1.00

Table 8-9

Correlation Matrix for the Bascunana Variables - Composite Data

Variable	CMPG	ETW[a]	DISP[b]	(N/V)[c]
CMPG	1.00			
ETW[a]	-.92	1.00		
DISP[b]	-.88	.95	1.00	
(N/V)[c]	.58	-.76	-.81	1.00

C. Summary

The multicollinearity present in the three equations implies that caution should be used in their application. Especially sensitive applications would be those involving predictions of the effect of individual variables or their use to to predict MPG from vehicles whose design parameters were not related in the same way as those design parameters are in the MY81 data base. However, such applications were not made for this report. The use of the equations, "played back" on the same data set from which their coefficients were based, is appropriate for the residual analysis that was done in section IV. For the use of the Cheng equation to generate "adjusted MPG" in section IV, it is assumed that the equation's coefficients developed from MY81 data are adequate for use on the MY79 and MY80 data bases also.

Appendix 9

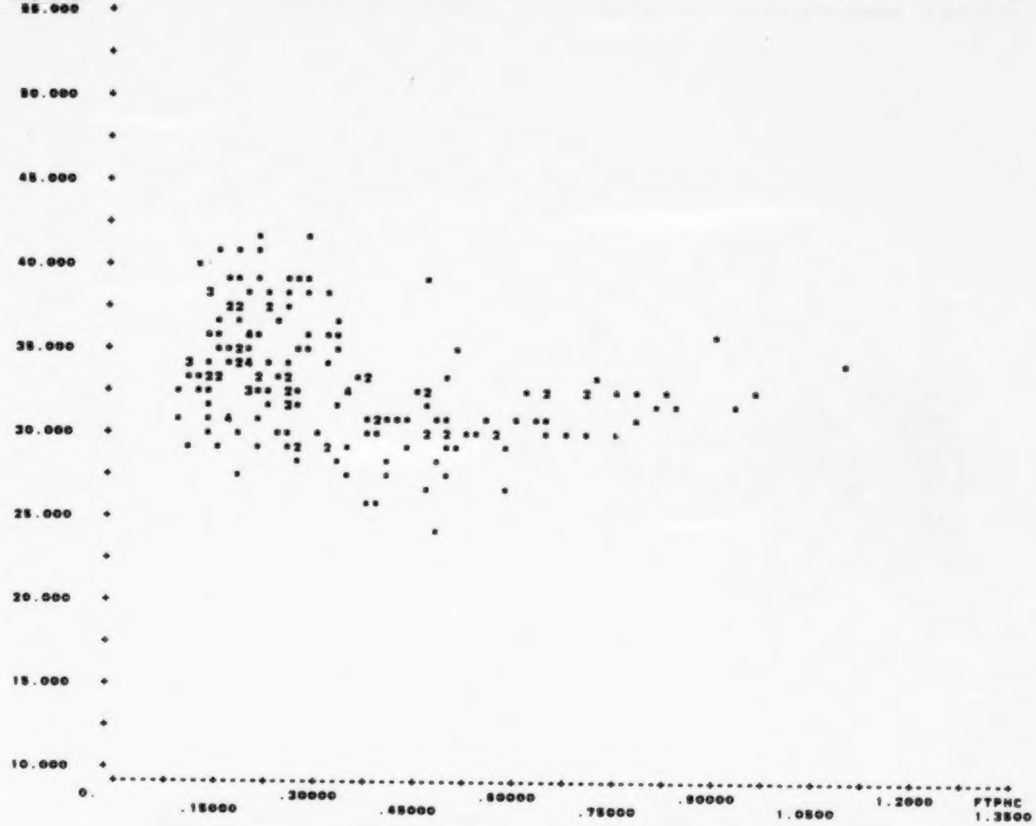
Plots of Ton-Miles per Gallon versus Emissions by Emission Control System

Two variable linear regression plots of Ton-Miles per Gallon for Urban Fuel Economy (UMPGETW) and Combined Fuel Economy (CMPGETW), each plotted agains FTPHC, FTPCO, and FTPNOX.

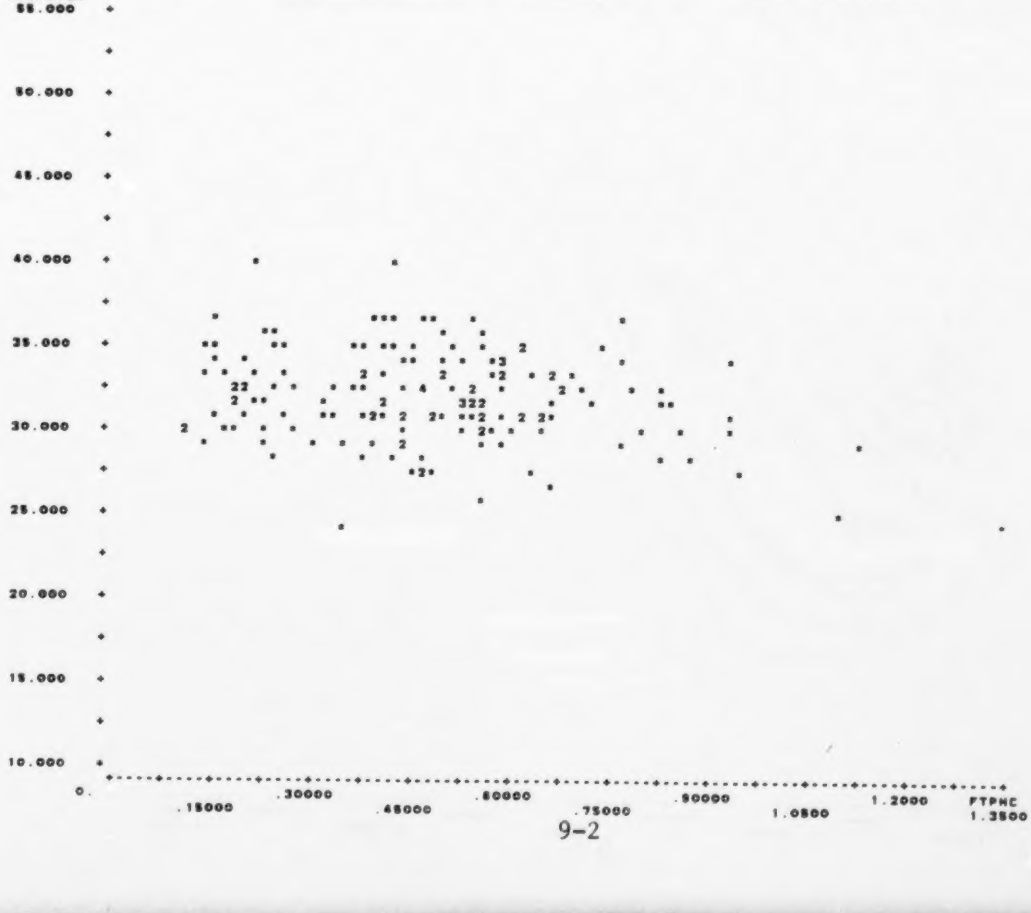
Data from EPA/CERT Data Base, restricted to non-durability, non-Diesel vehicles of test active years 1979, 1980, and 1981 were used.

Stratification by emission control system. (See Section IV. H.)

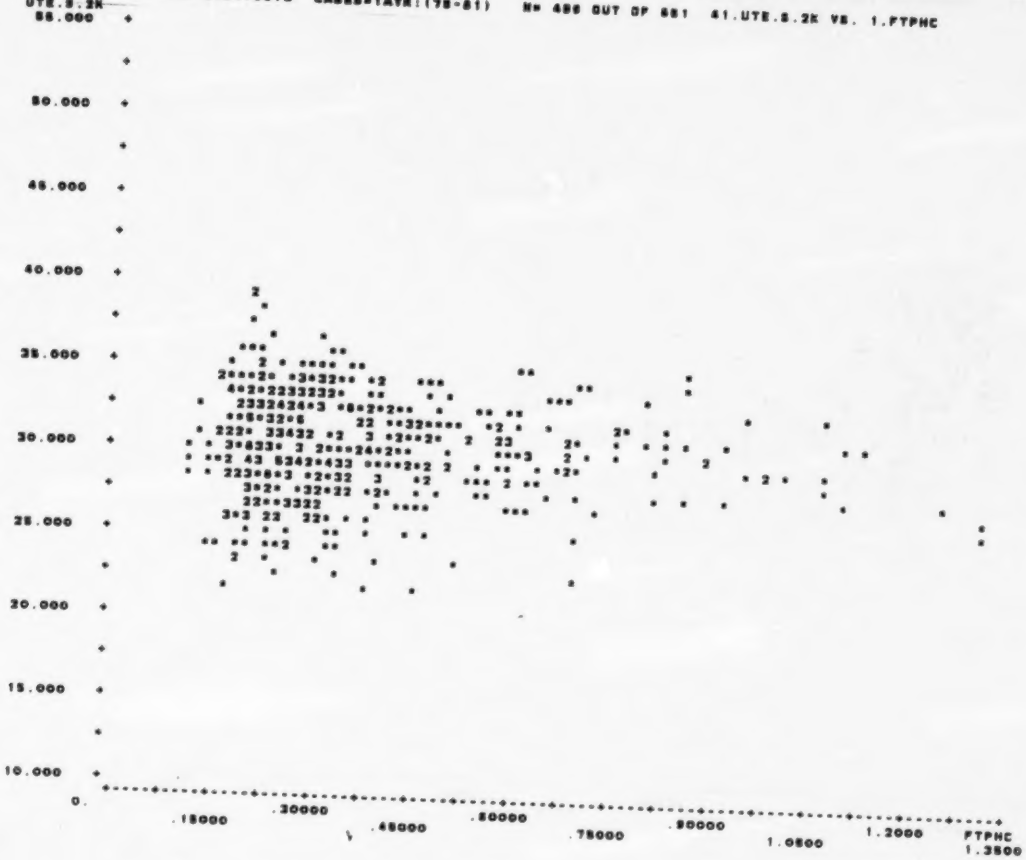
(SCATTER SYST VAR=41;1 CASES=V80:(79-81) STRAT=V102 (1) SYS1TD8:1 CASES=TAYR:(79-81) N= 188 OUT OF 248 41.UTE.S.2K VS. 1.FTPHC



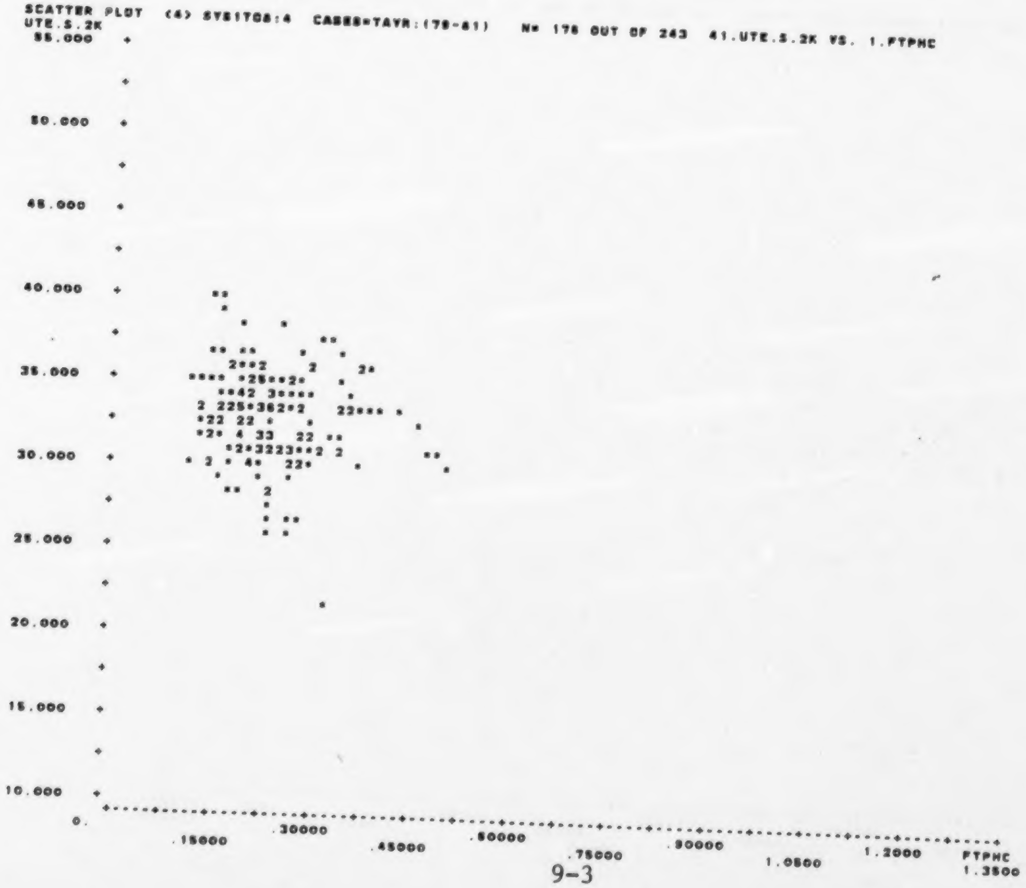
SCATTER PLOT (2) SYS1TD8:2 CASES=TAYR:(79-81) N= 188 OUT OF 229 41.UTE.S.2K VS. 1.FTPHC



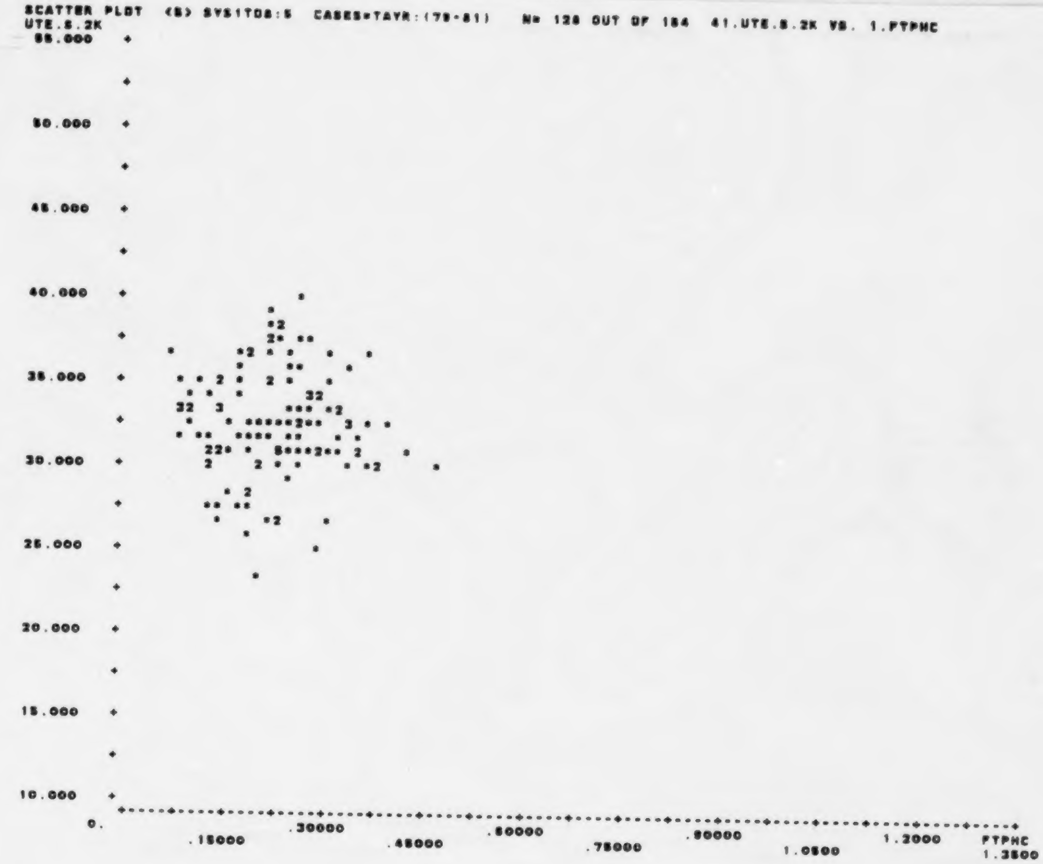
SCATTER PLOT (3) SYS1TO8:3 CASES=TAYR:(79-81) N= 486 OUT OF 681 41.UTE.S.2K VS. 1.FTPHC



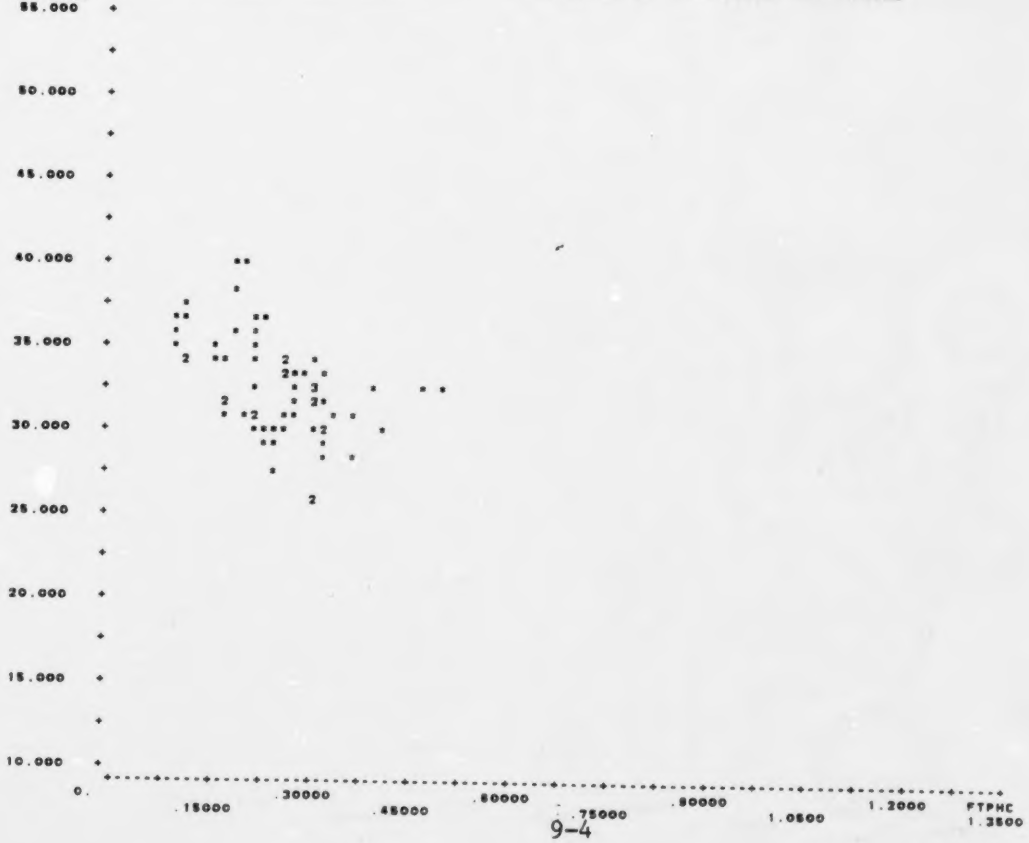
SCATTER PLOT (4) SYS1TO8:4 CASES=TAYR:(79-81) N= 178 OUT OF 243 41.UTE.S.2K VS. 1.FTPHC



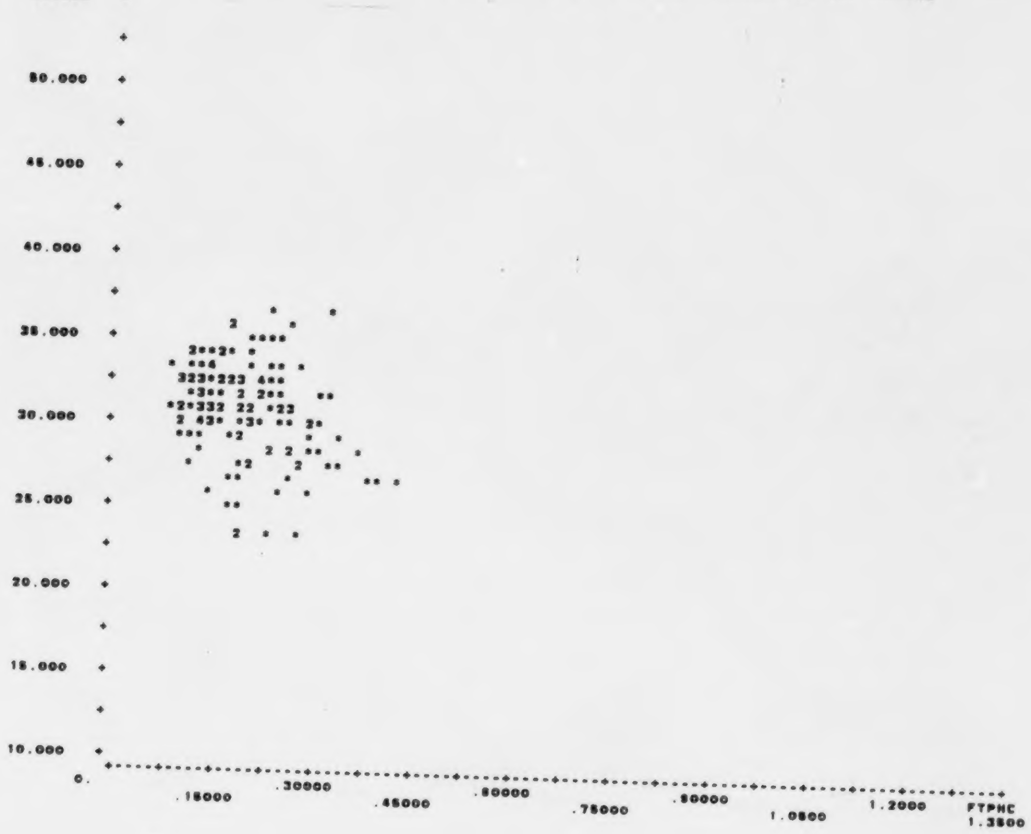
SCATTER PLOT <S> SYS1TOS:5 CASES=TAYR:(79-81) N= 128 OUT OF 184 41.UTE.S.2K VS. 1.FTPHC



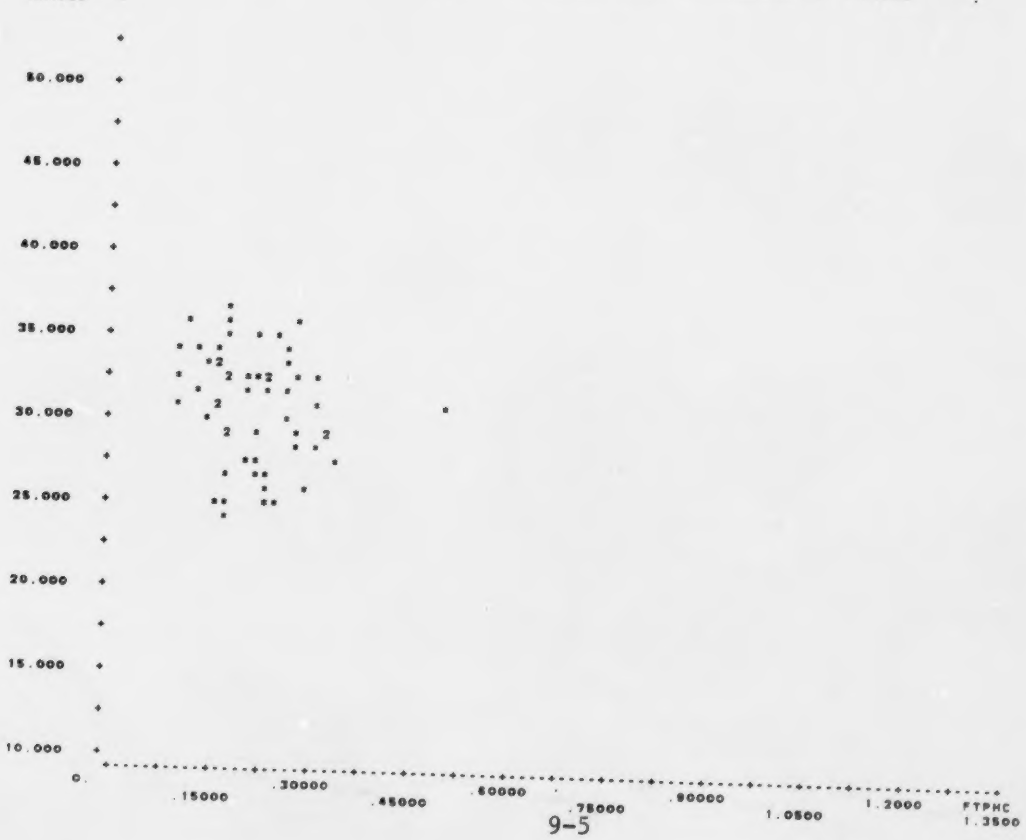
SCATTER PLOT <S> SYS1TOS:6 CASES=TAYR:(79-81) N= 55 OUT OF 88 41.UTE.S.2K VS. 1.FTPHC



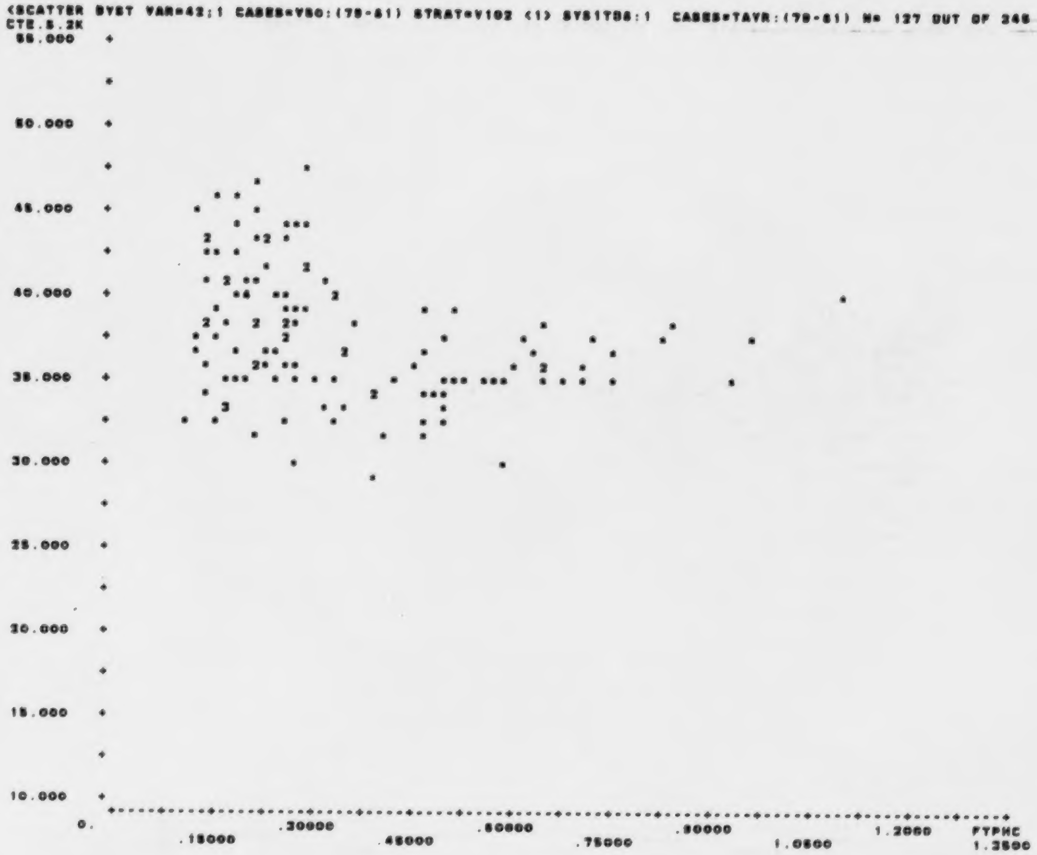
SCATTER PLOT (7) SYSITOS:7 CASES=TAYR:(78-81) N= 145 OUT OF 203 41.UTE.S.2K VS. 1.FTPHC



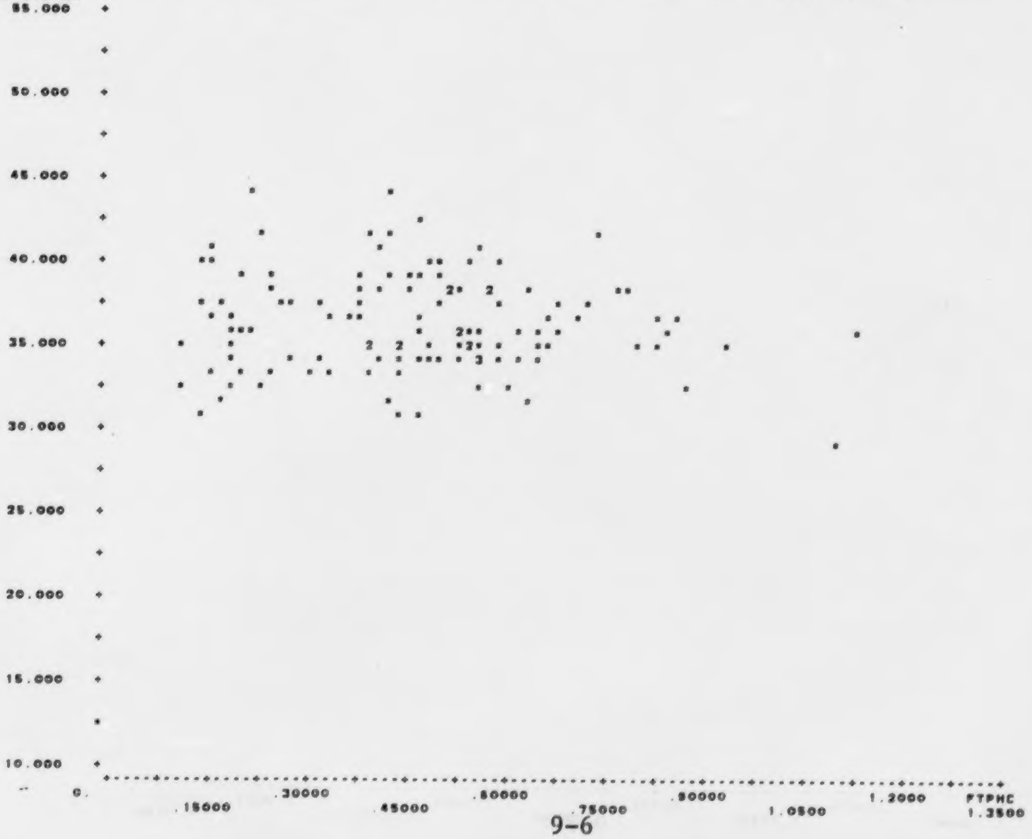
SCATTER PLOT (8) SYSITOS:8 CASES=TAYR:(78-81) N= 56 OUT OF 78 41.UTE.S.2K VS. 1.FTPHC



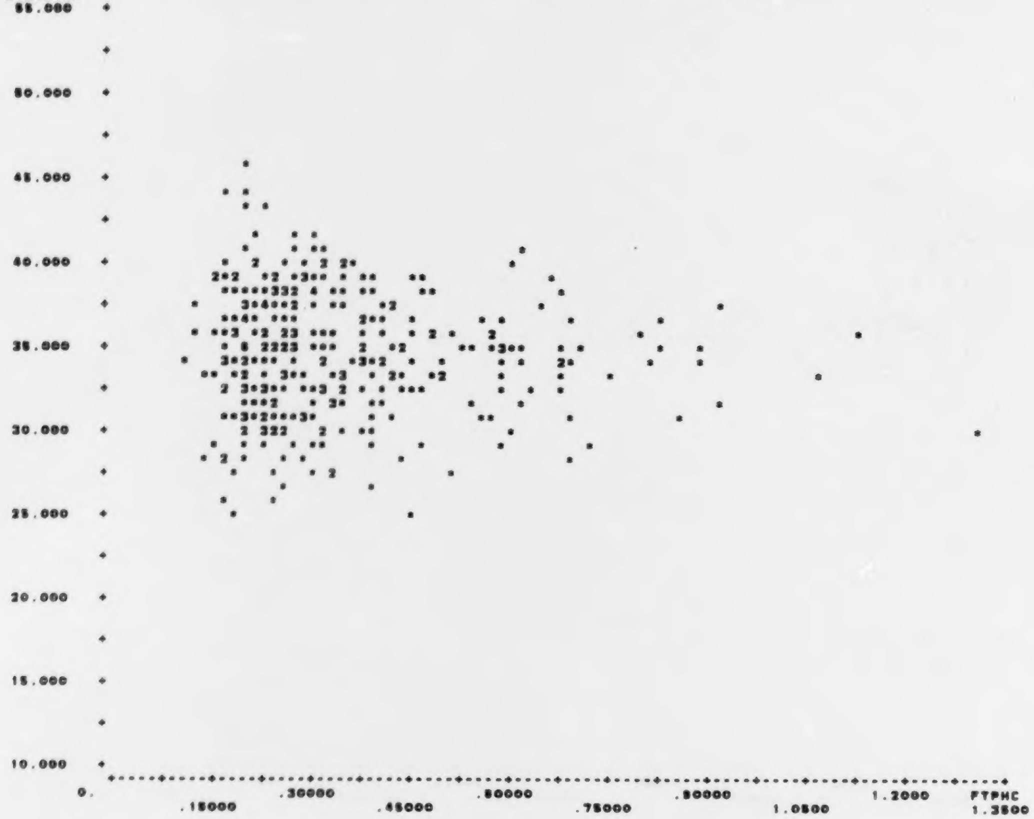
(SCATTER SYST VAR=42;1 CASES=VSO:(79-81) STRAT=V102 (1) SYS1TDS:1 CASES=TAVR:(79-81) N= 127 OUT OF 246 42.CTE.S.2K VS. 1.FTPHC



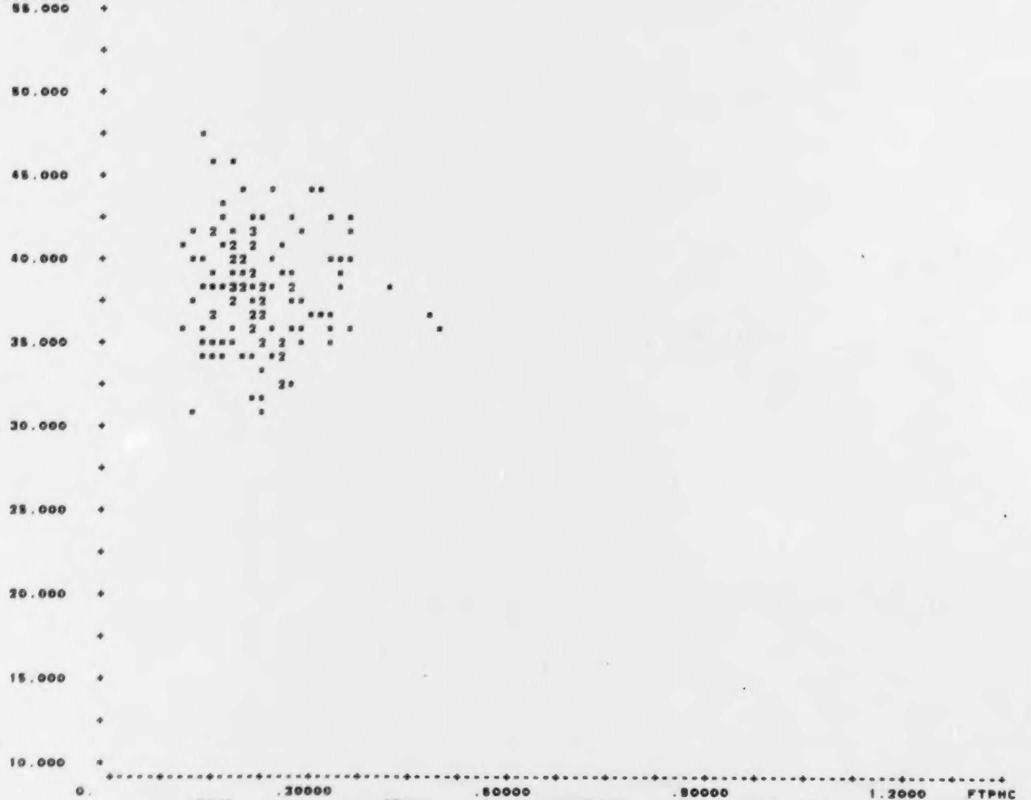
SCATTER PLOT (2) SYS1TDS:2 CASES=TAVR:(79-81) N= 120 OUT OF 229 42.CTE.S.2K VS. 1.FTPHC



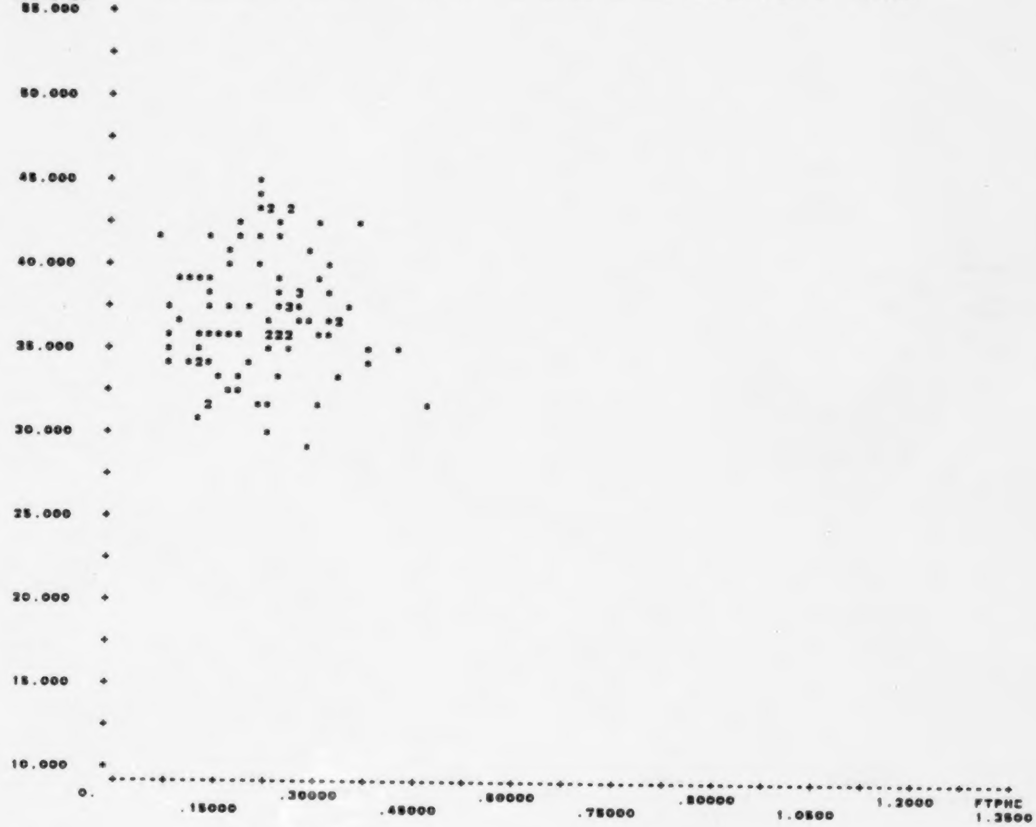
SCATTER PLOT (3) SYS1TOS:3 CASES=TAVR:(79-81) N= 334 OUT OF 881 42.CTE.S.2K VS. 1.FTPHC



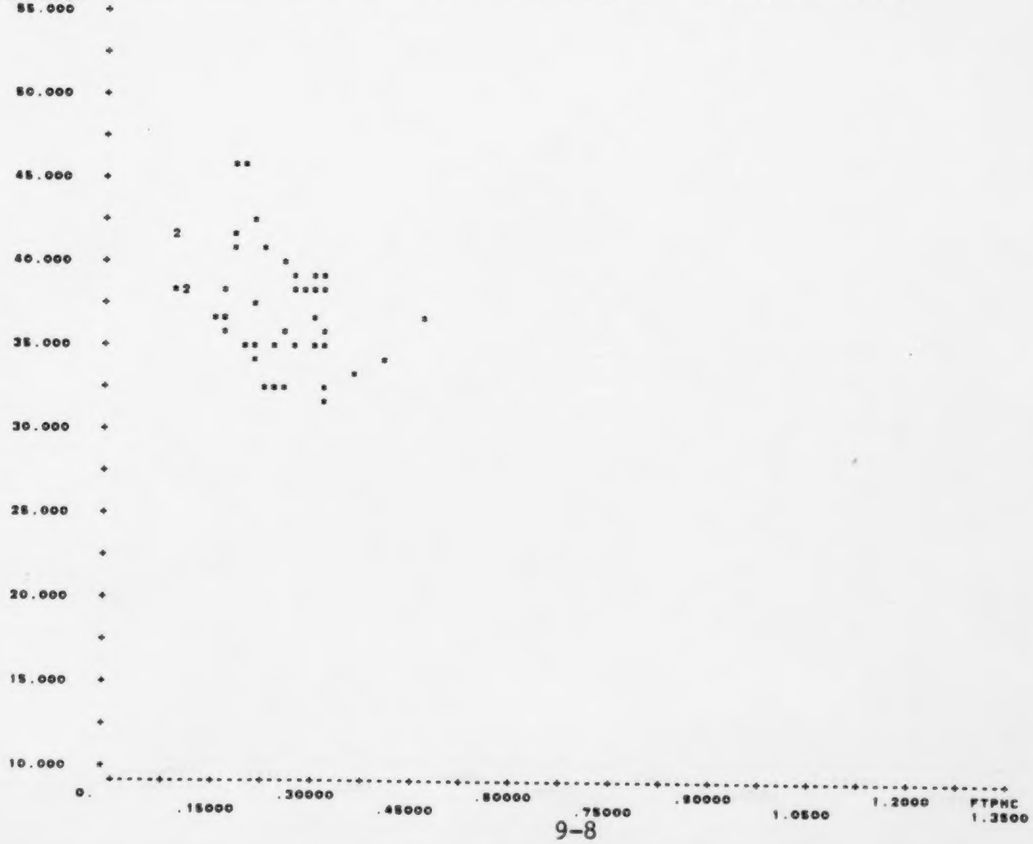
SCATTER PLOT (4) SYS1TOS:4 CASES=TAVR:(79-81) N= 118 OUT OF 243 42.CTE.S.2K VS. 1.FTPHC



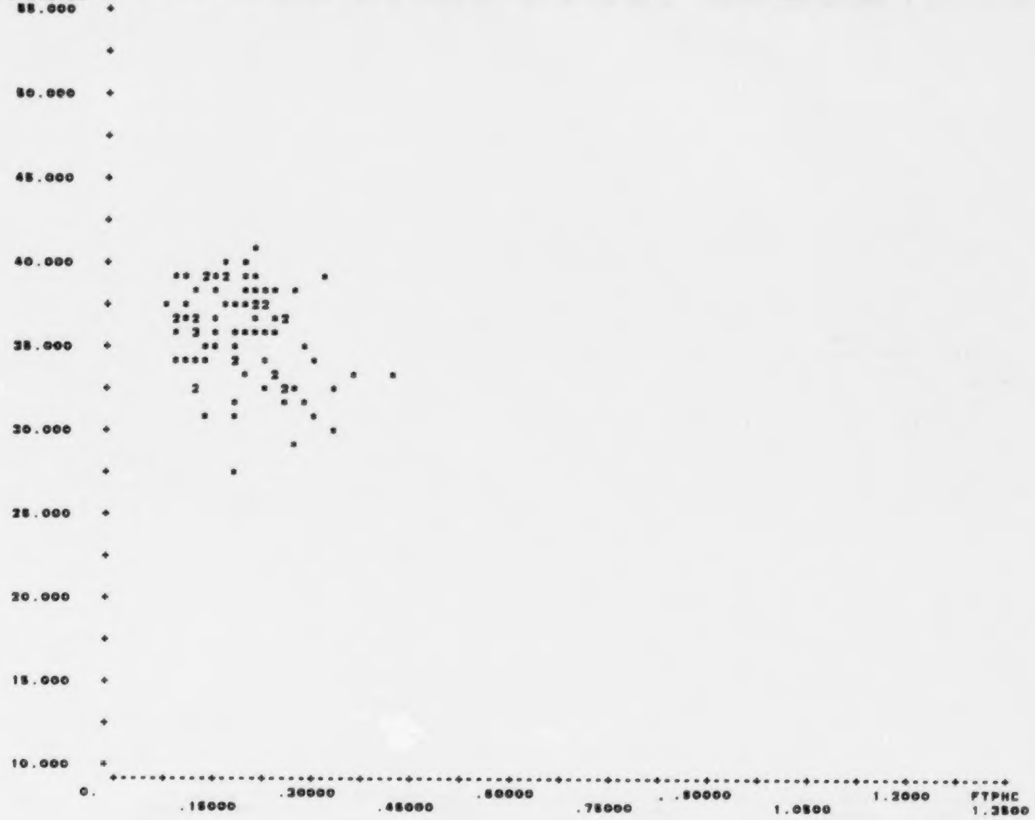
SCATTER PLOT (5) SYS1TD8:5 CASES=TAYR:(79-81) N= 82 OUT OF 184 42.CTE.S.2K VS. 1.FTPHC



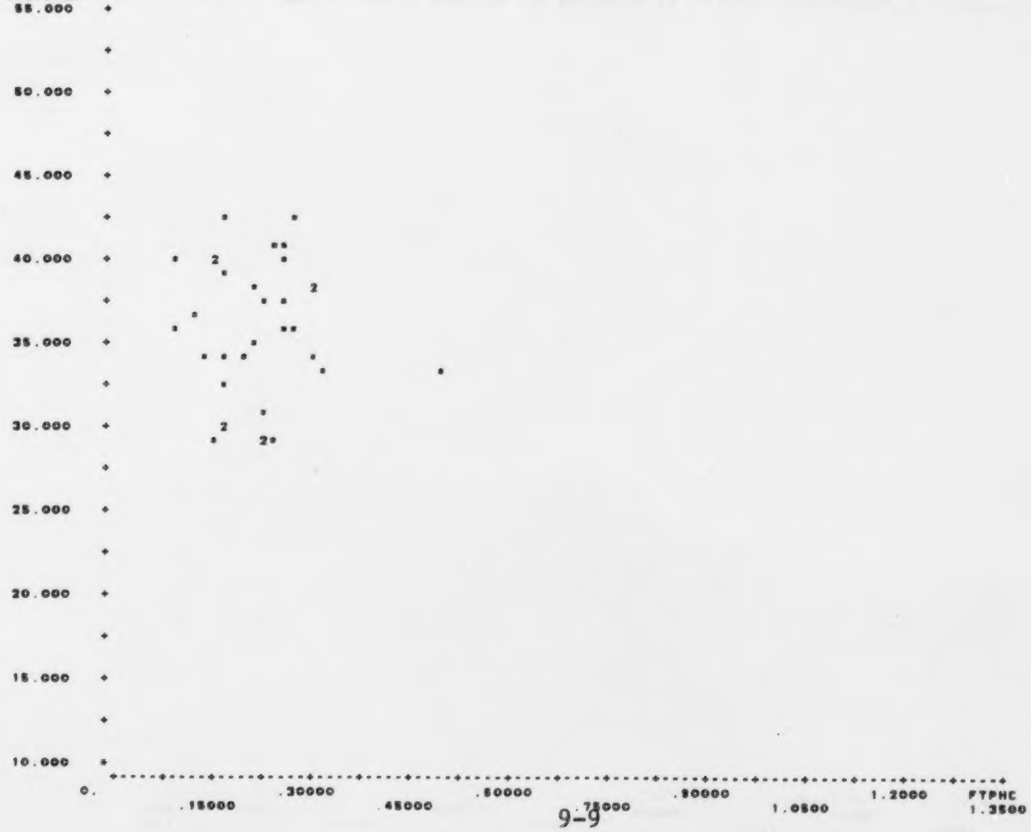
SCATTER PLOT (6) SYS1TD8:6 CASES=TAYR:(79-81) N= 42 OUT OF 88 42.CTE.S.2K VS. 1.FTPHC



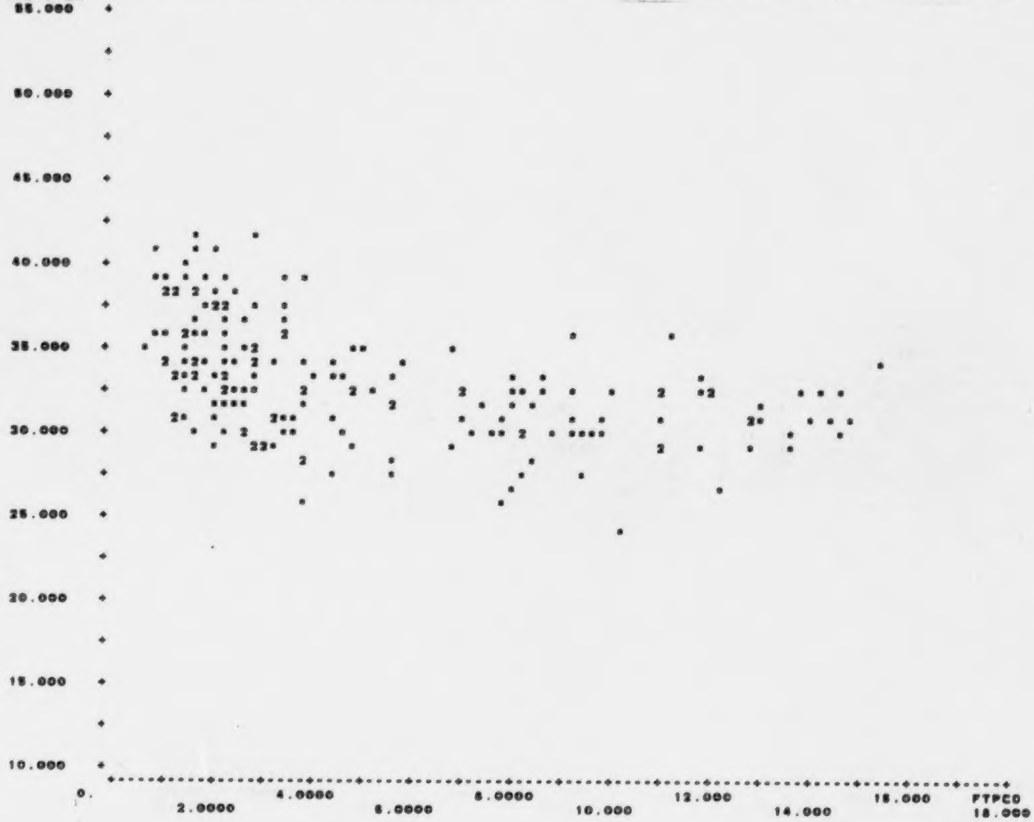
SCATTER PLOT (7) SYS1TD8:7 CASES=TAYR:(79-81) N= 82 OUT OF 203 42.CTE.S.2K VS. 1.FTPHC



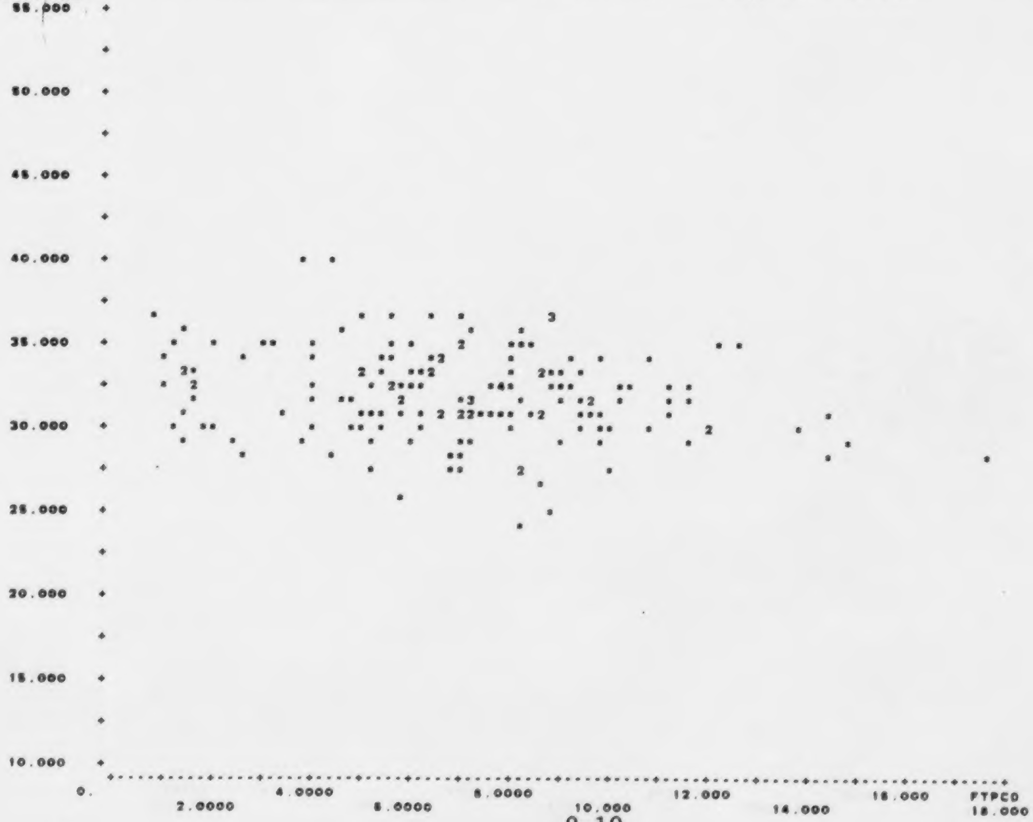
SCATTER PLOT (8) SYS1TD8:8 CASES=TAYR:(79-81) N= 33 OUT OF 78 42.CTE.S.2K VS. 1.FTPHC



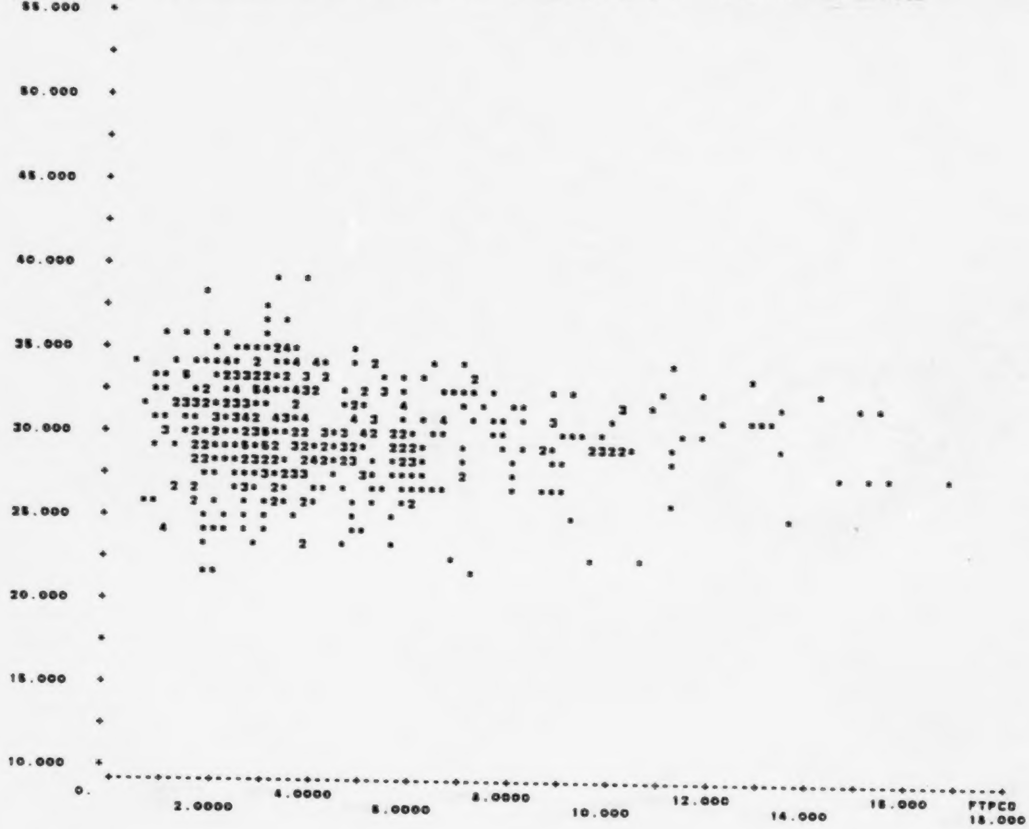
<SCATTER SYST VAR=41;2 CASES=Y80:(79-81) STRAT=Y102 (1) SYS1TDS:1 CASES=TAYR:(79-81) N= 185 OUT OF 245 41.UTE.S.2K VS. 2.FTPCD



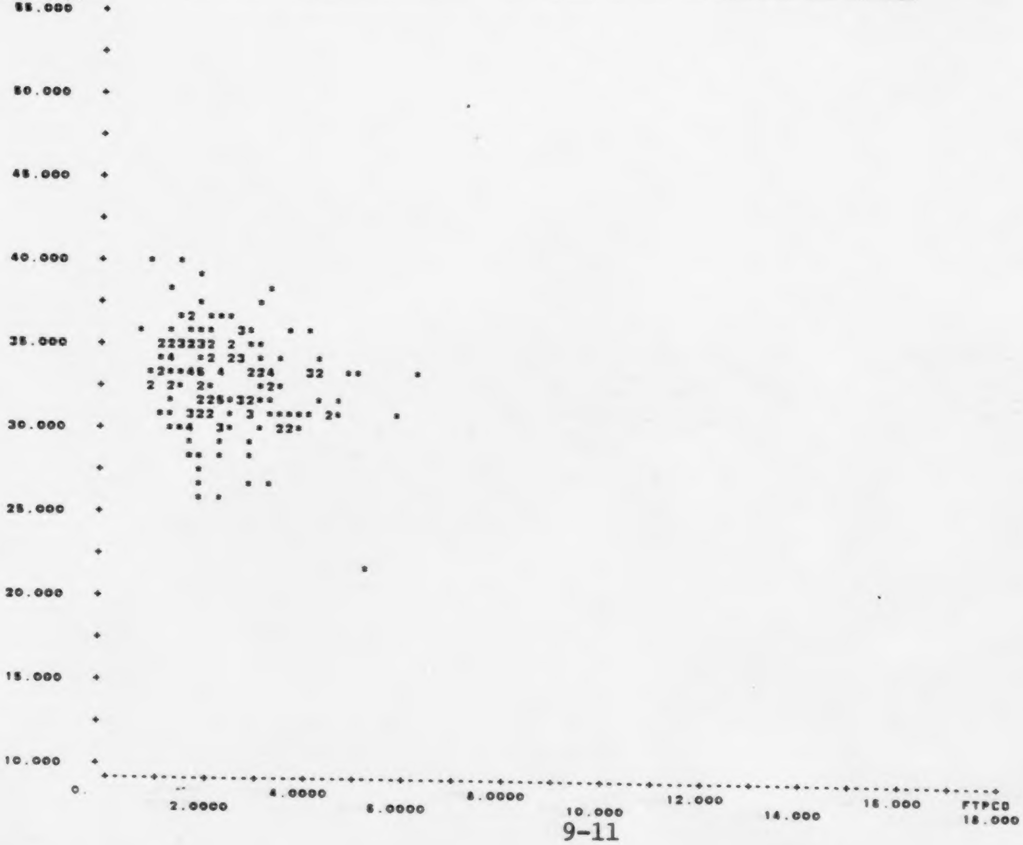
SCATTER PLOT (2) SYS1TDS:2 CASES=TAYR:(79-81) N= 186 OUT OF 229 41.UTE.S.2K VS. 2.FTPCD



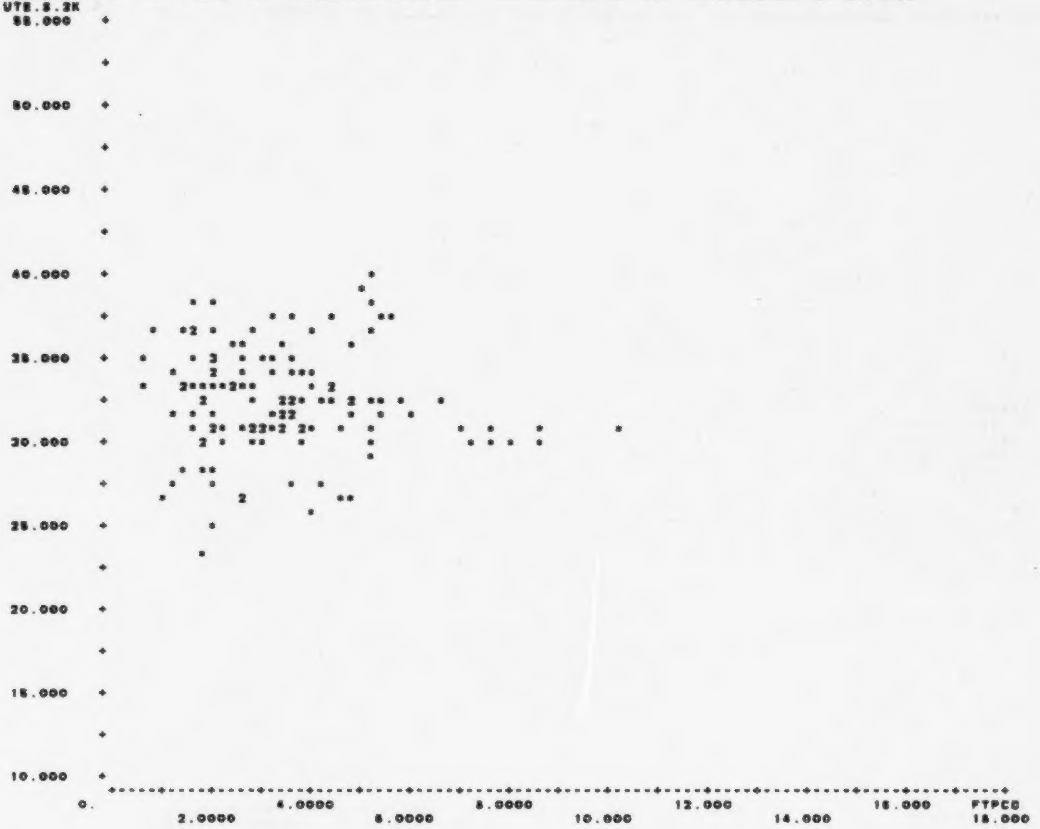
SCATTER PLOT (3) SYS1T08:3 CASES=TAYR:(78-81) N= 802 OUT OF 881 41.UTE.S.2K VS. 2.FTPCD



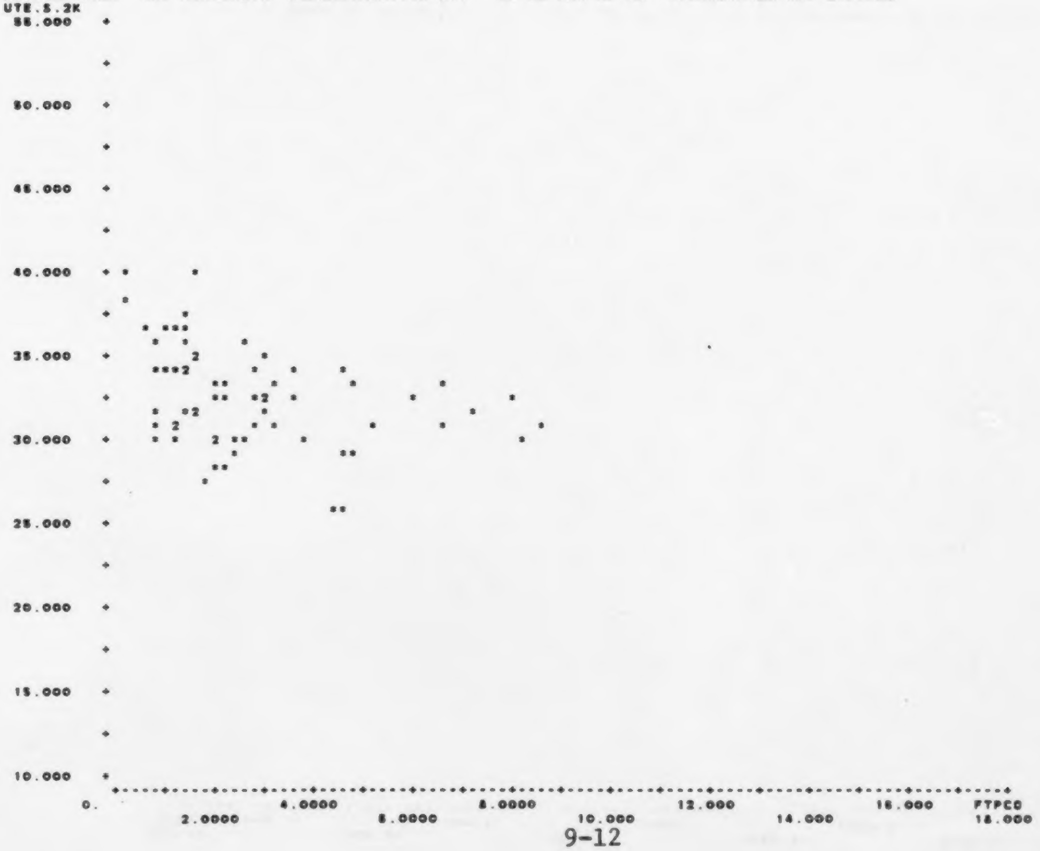
SCATTER PLOT (4) SYS1T08:4 CASES=TAYR:(78-81) N= 178 OUT OF 243 41.UTE.S.2K VS. 2.FTPCD



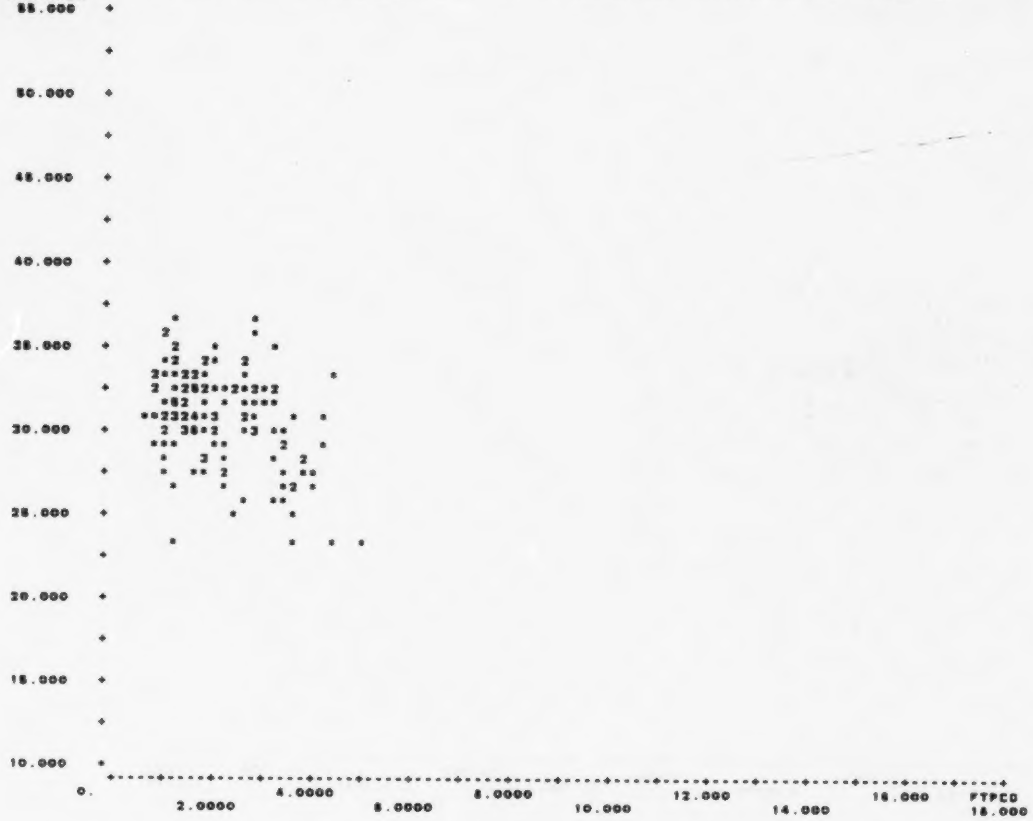
SCATTER PLOT <5> SYS1TD8:5 CASES=TAYR:(79-81) N= 128 OUT OF 184 41.UTE.S.2K VS. 2.FTPCD



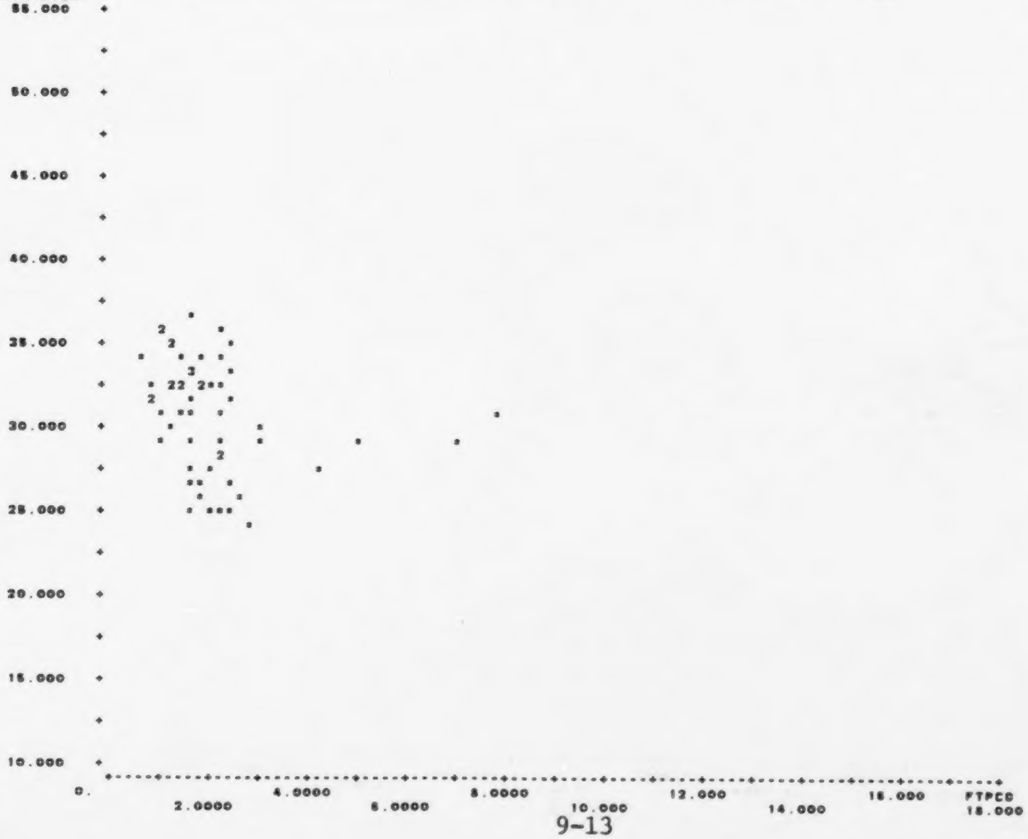
SCATTER PLOT <6> SYS1TD8:6 CASES=TAYR:(79-81) N= 55 OUT OF 88 41.UTE.S.2K VS. 2.FTPCD



SCATTER PLOT (7) SYS1TD8:7 CASES=TAYR:(78-81) N= 145 OUT OF 203 41.UTE.S.2K VS. 2.FTPCD



SCATTER PLOT (8) SYS1TD8:8 CASES=TAYR:(78-81) N= 55 OUT OF 78 41.UTE.S.2K VS. 2.FTPCD



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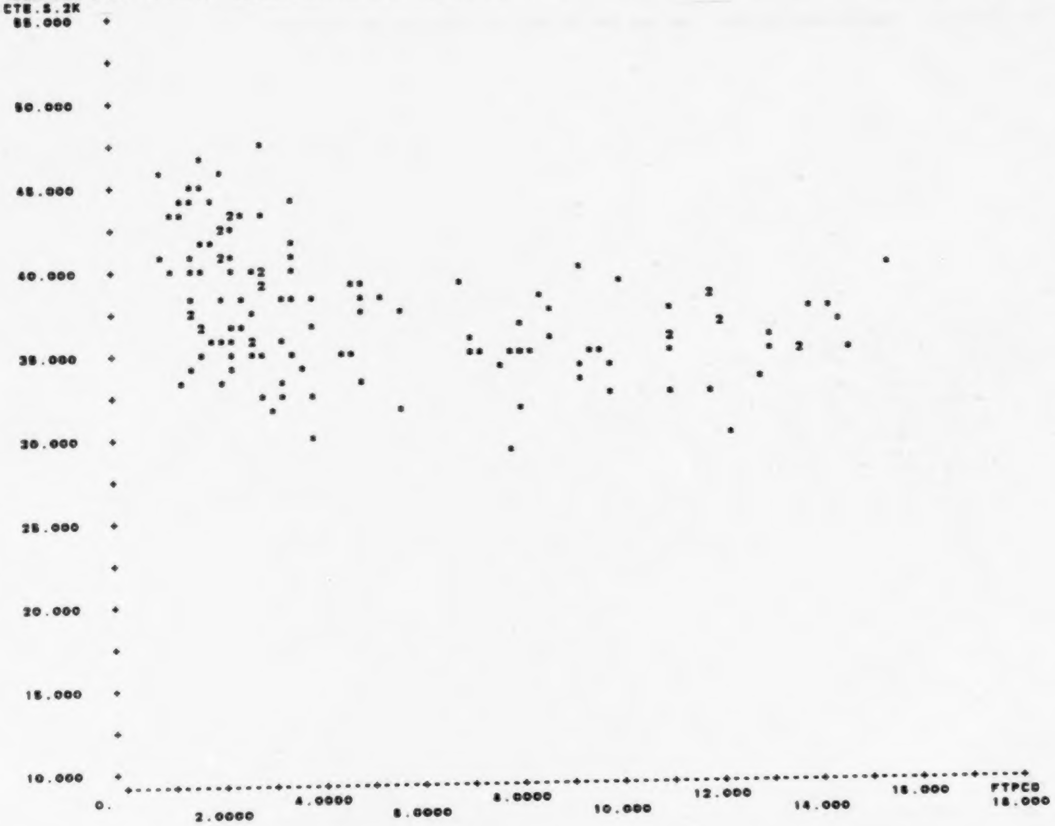

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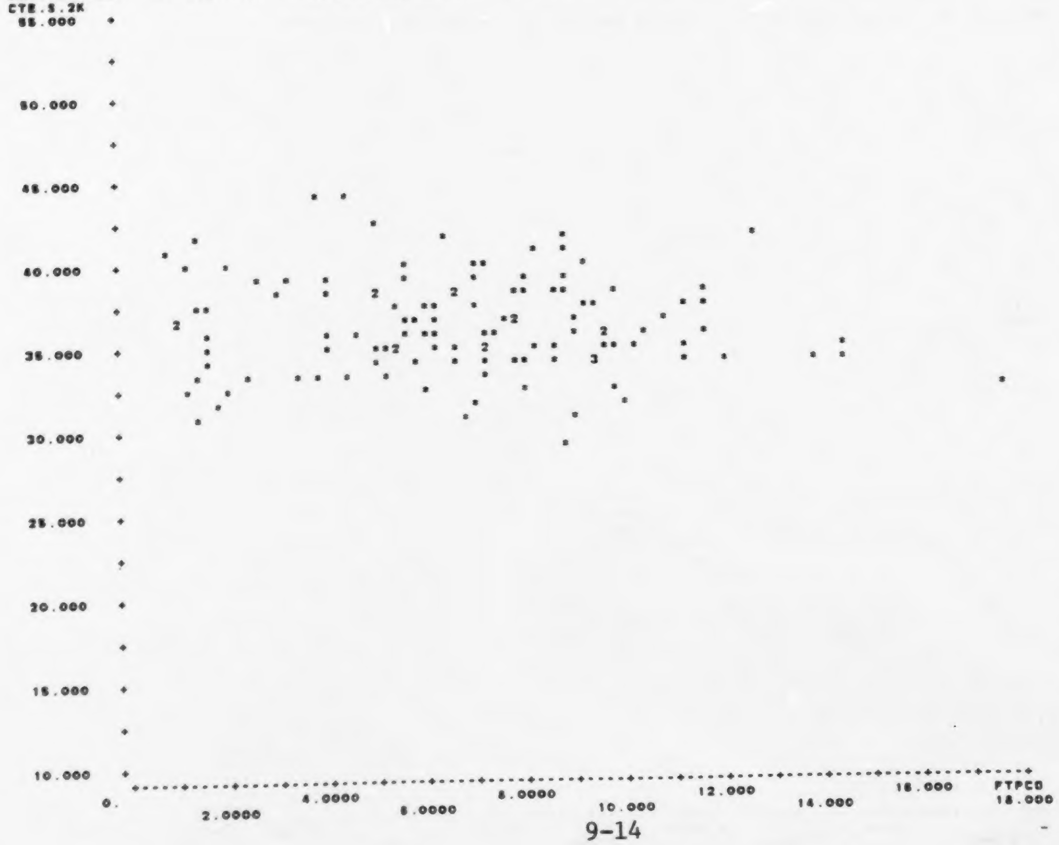

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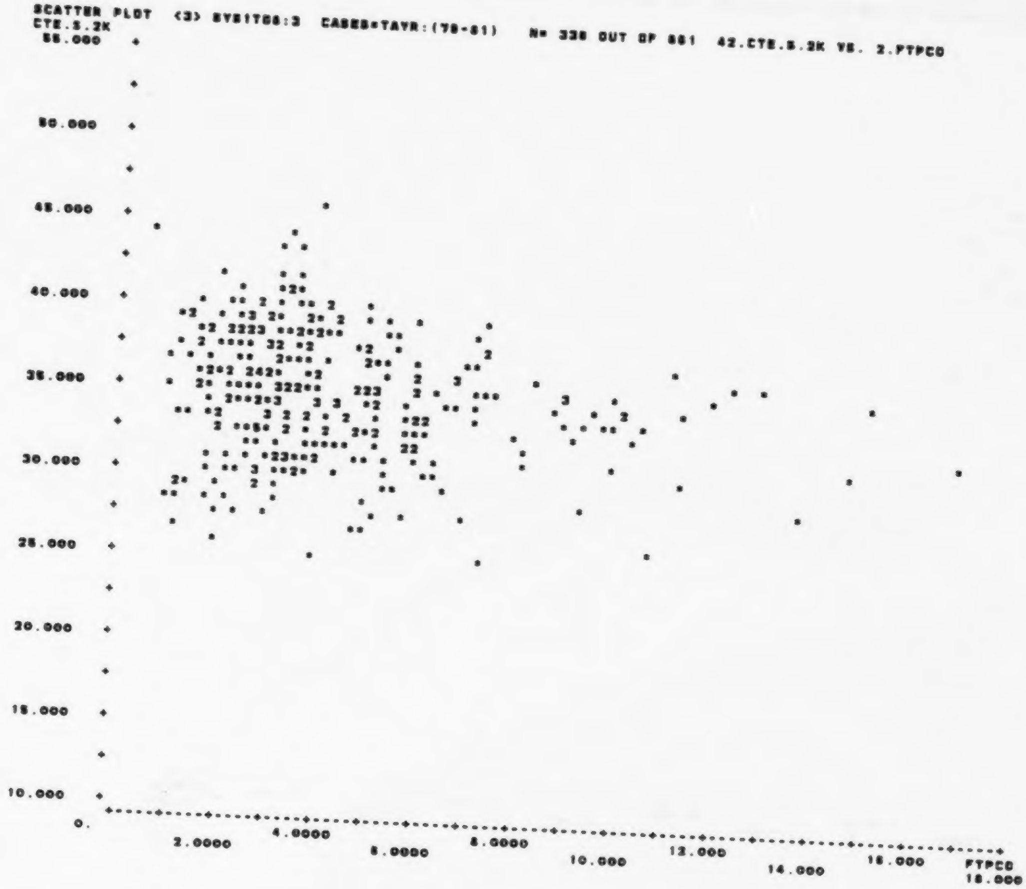

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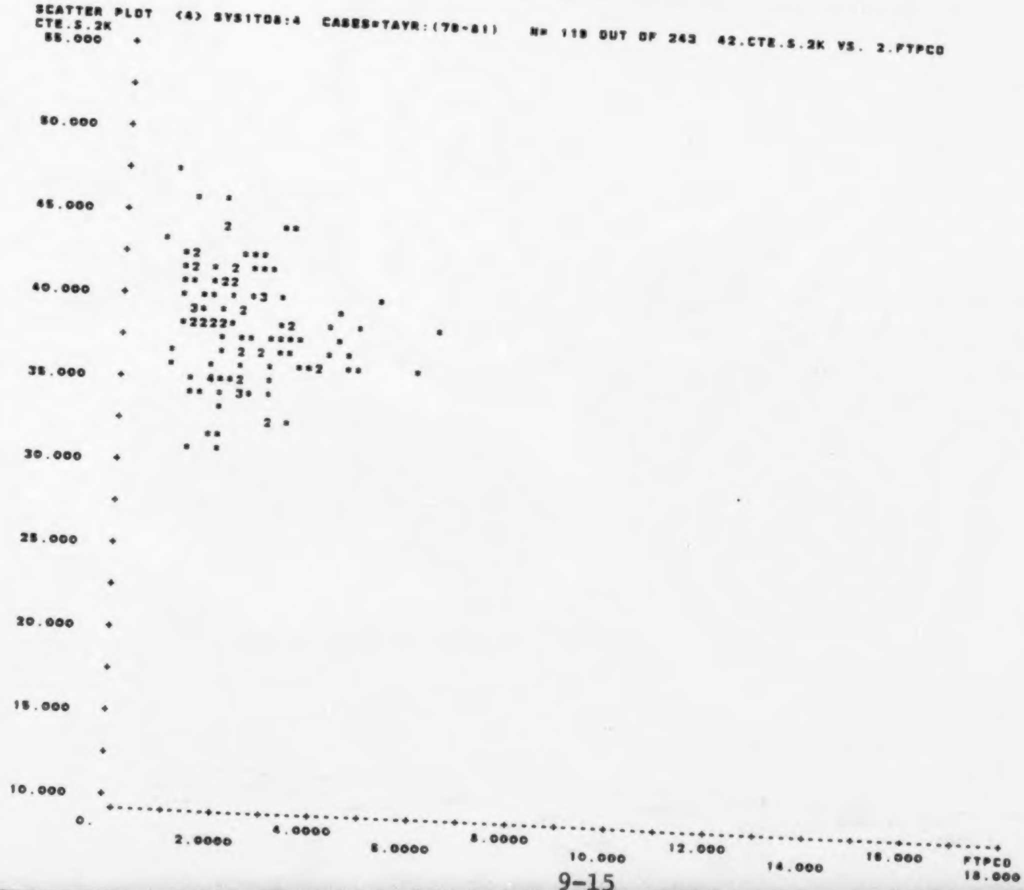

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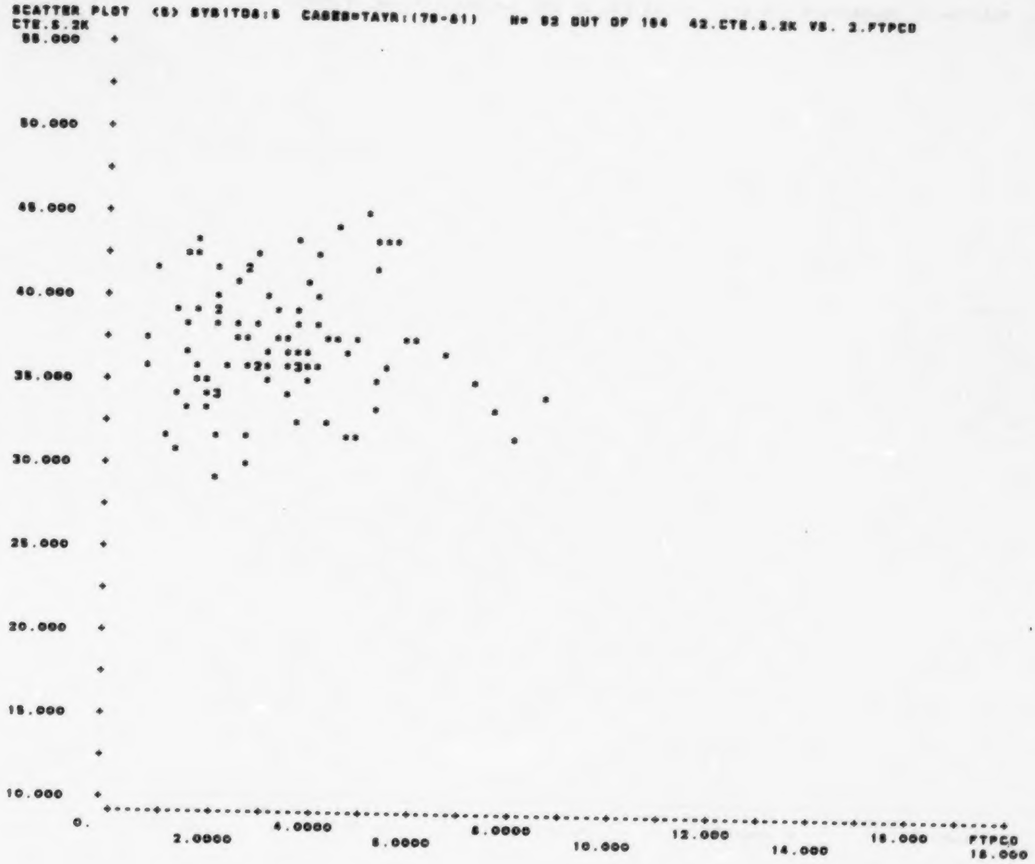

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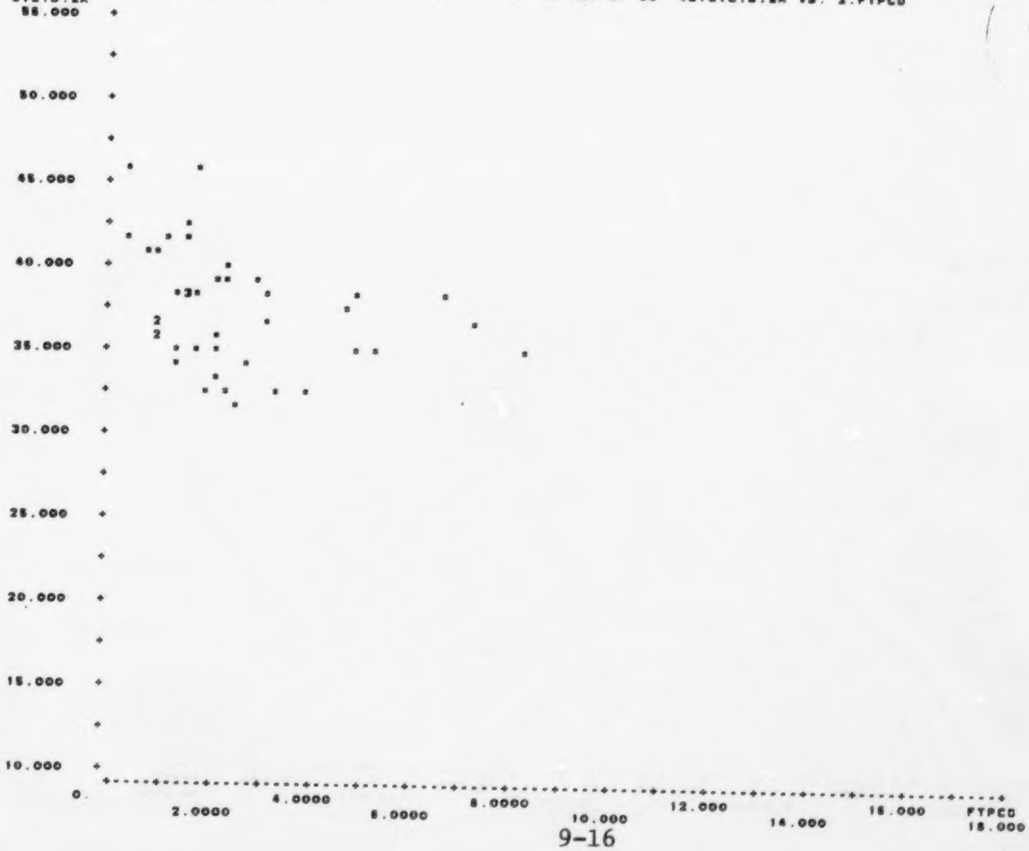

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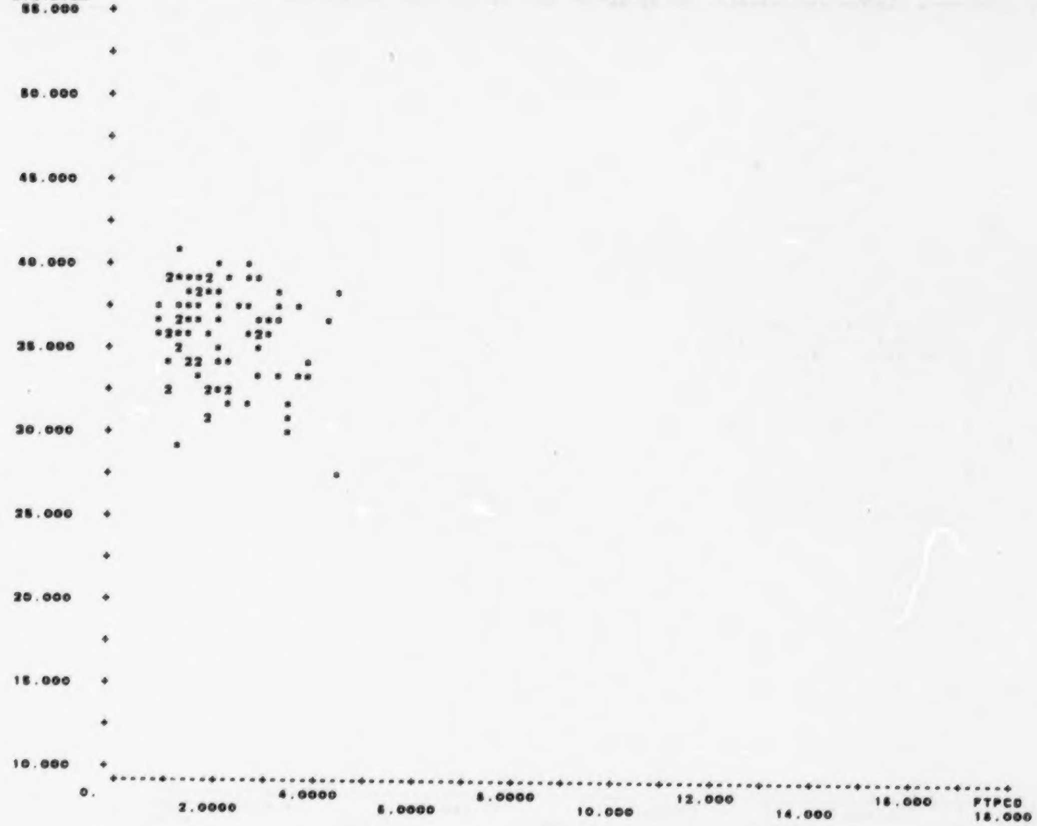

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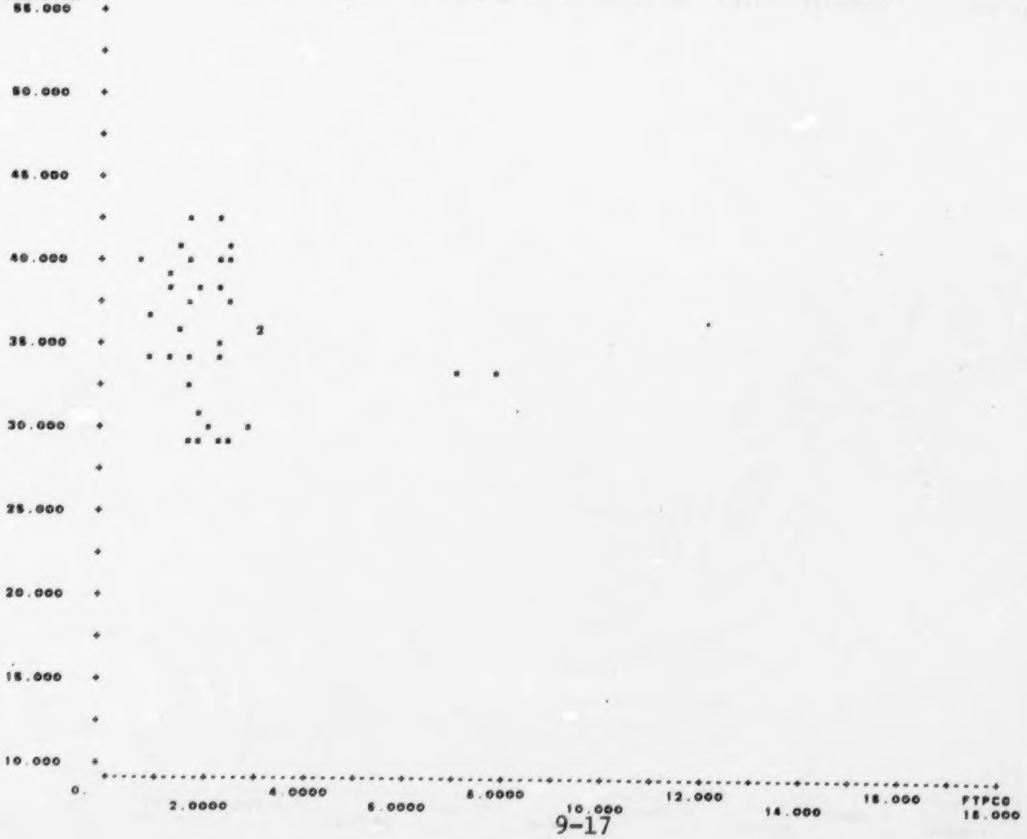

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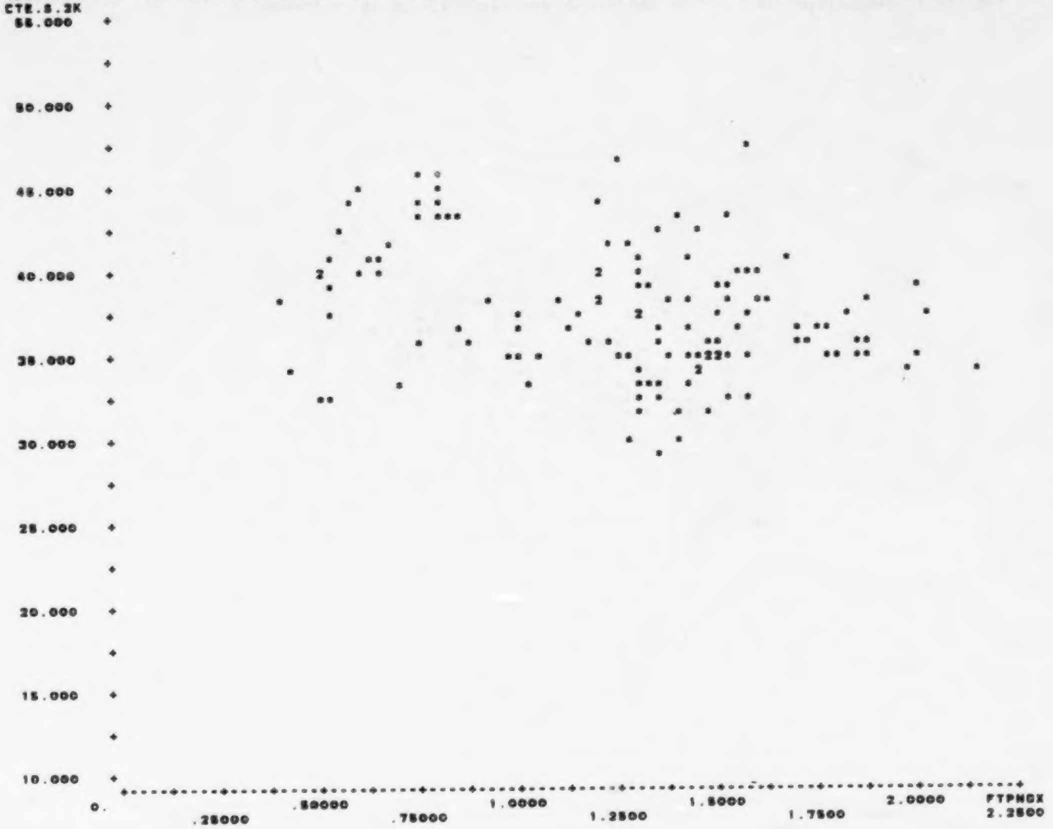

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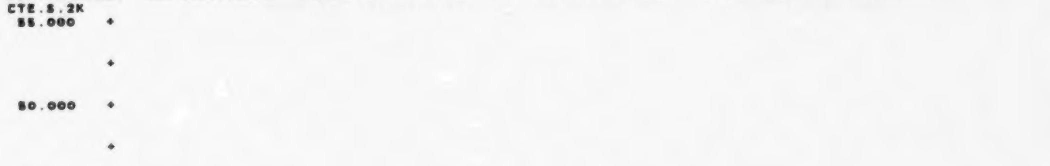

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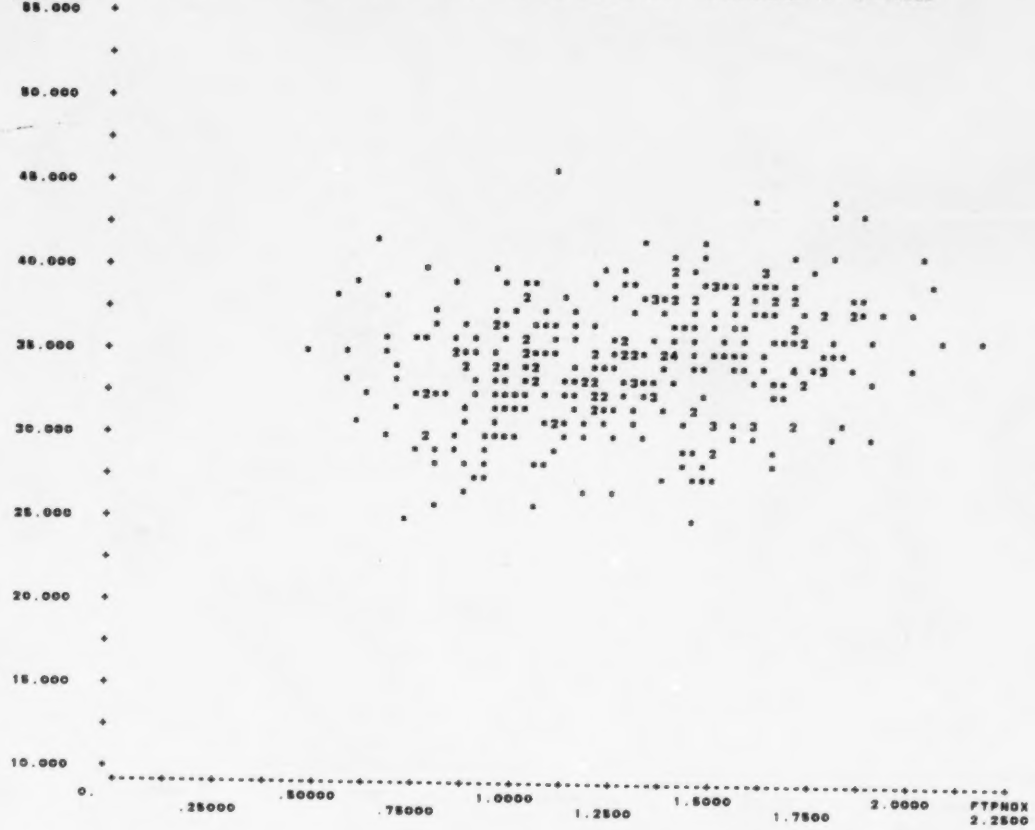

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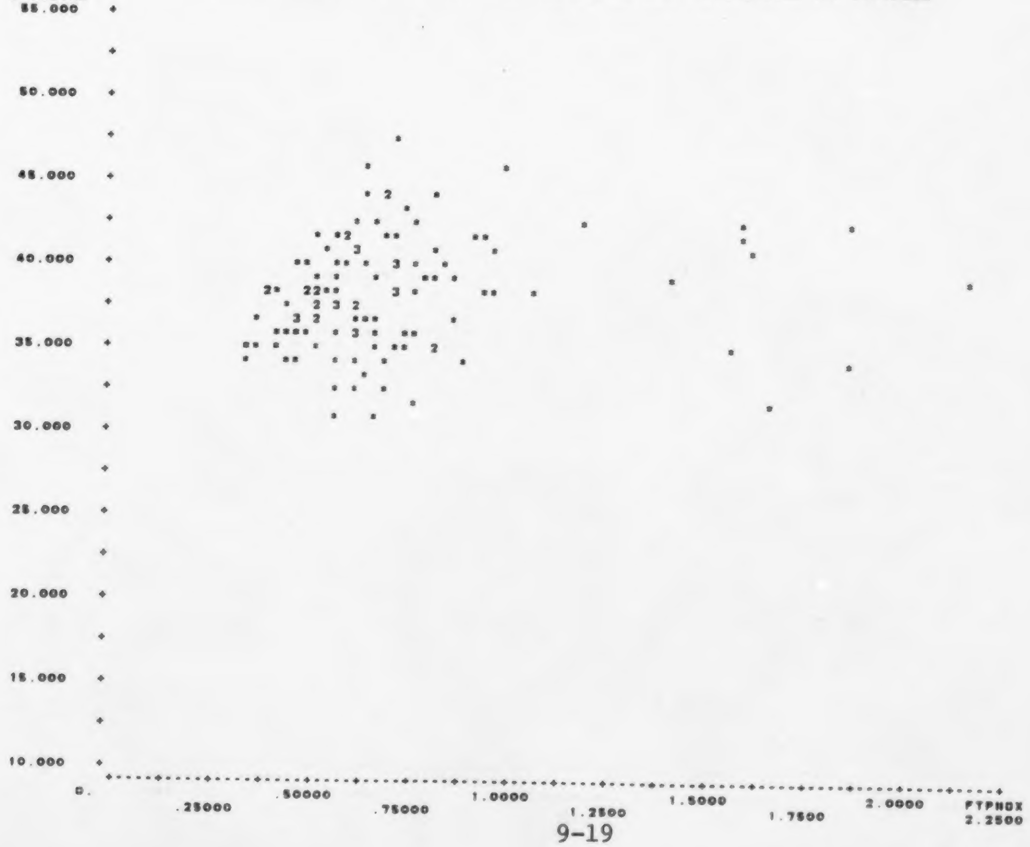

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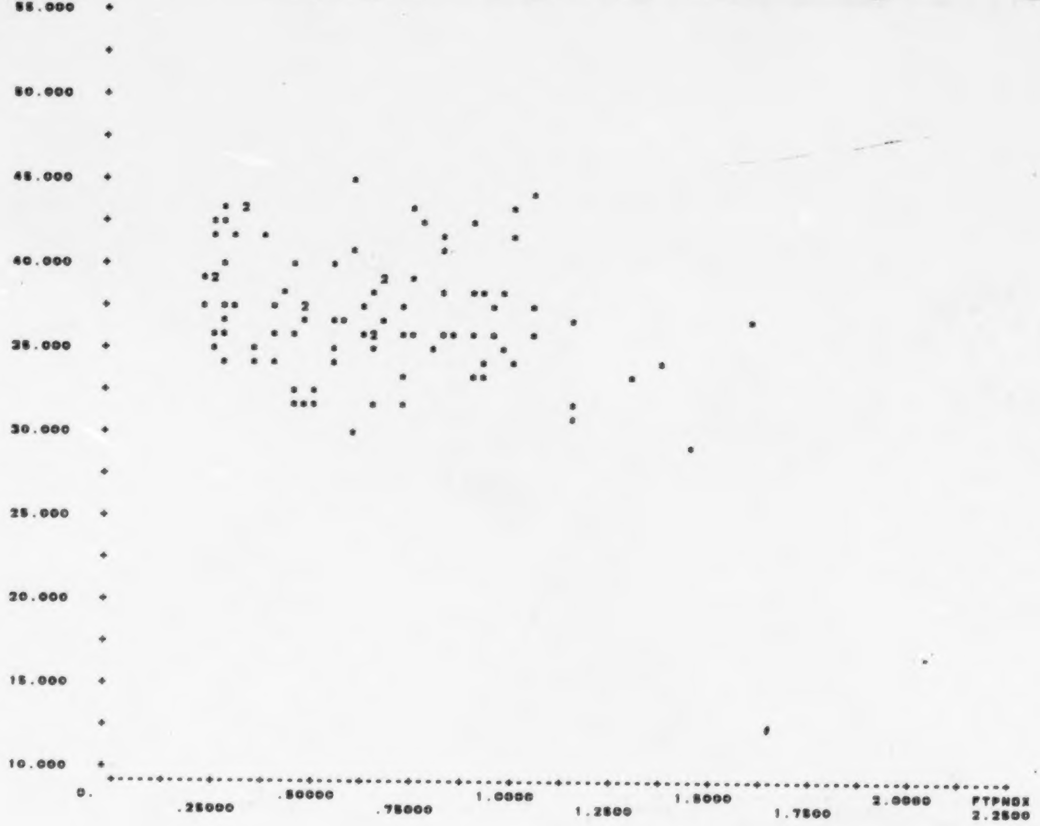

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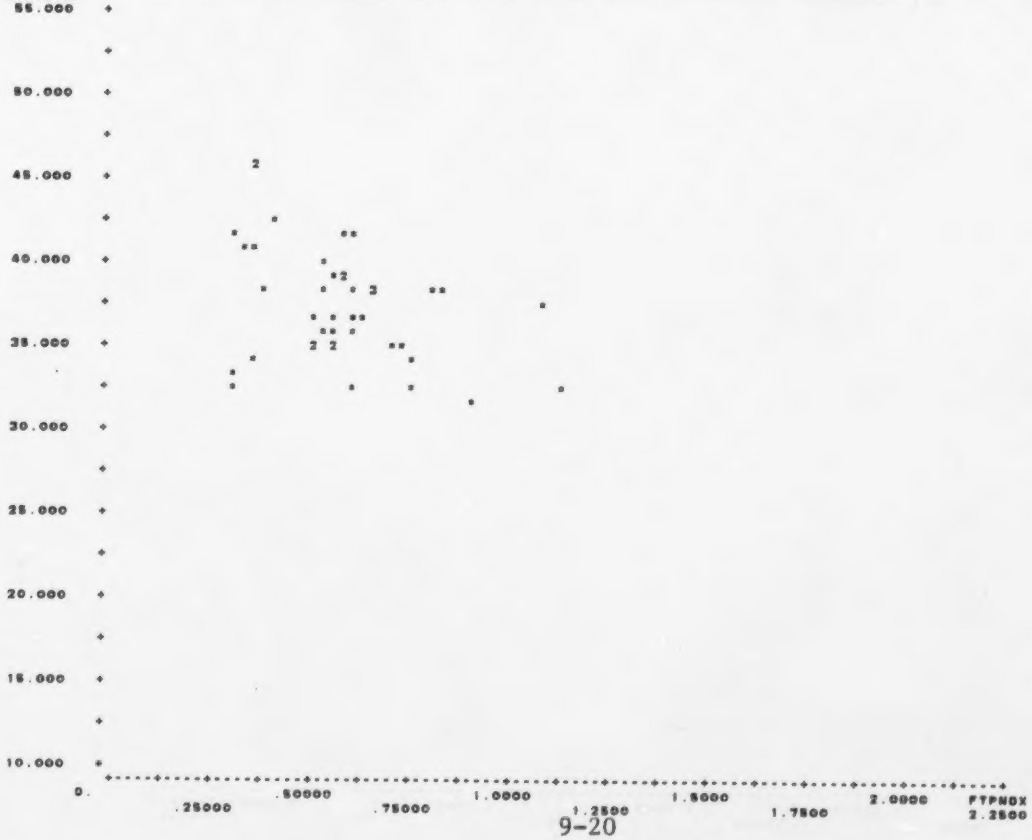
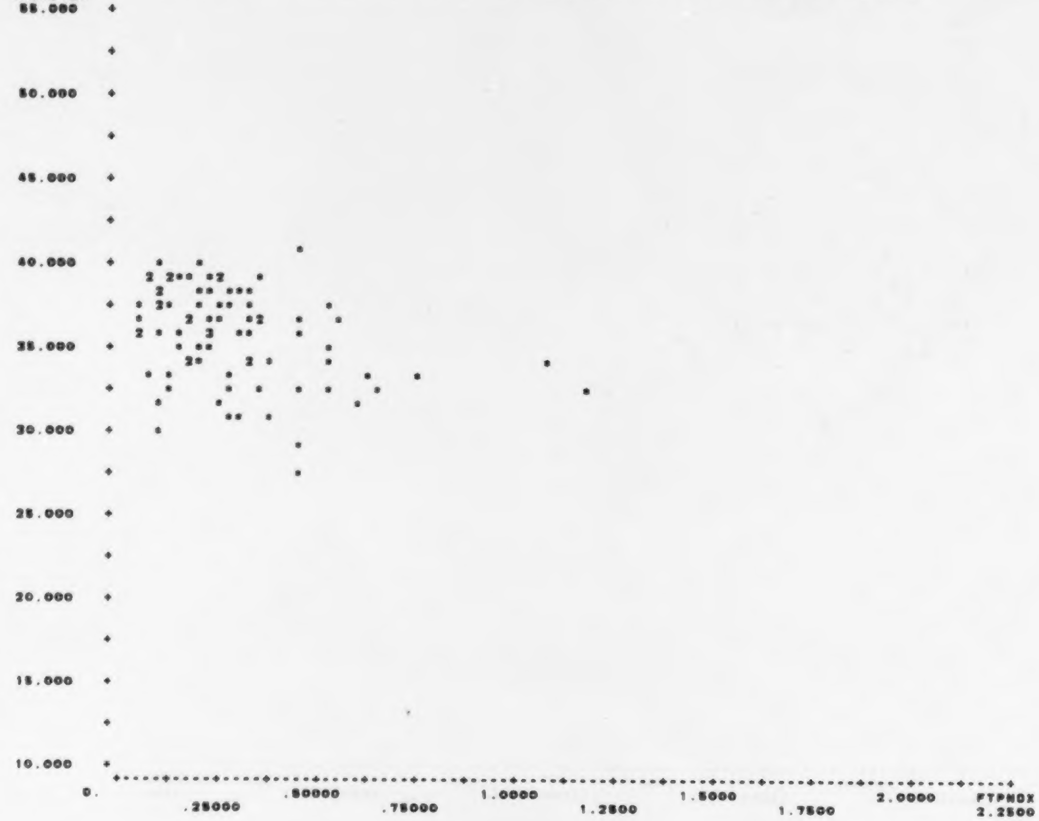


SCATTER PLOT (7) SYS1T08:7 CASES=TAYR:(79-81) N= 82 OUT OF 203 42.CTE.S.2K VS. 3.FTPNOX



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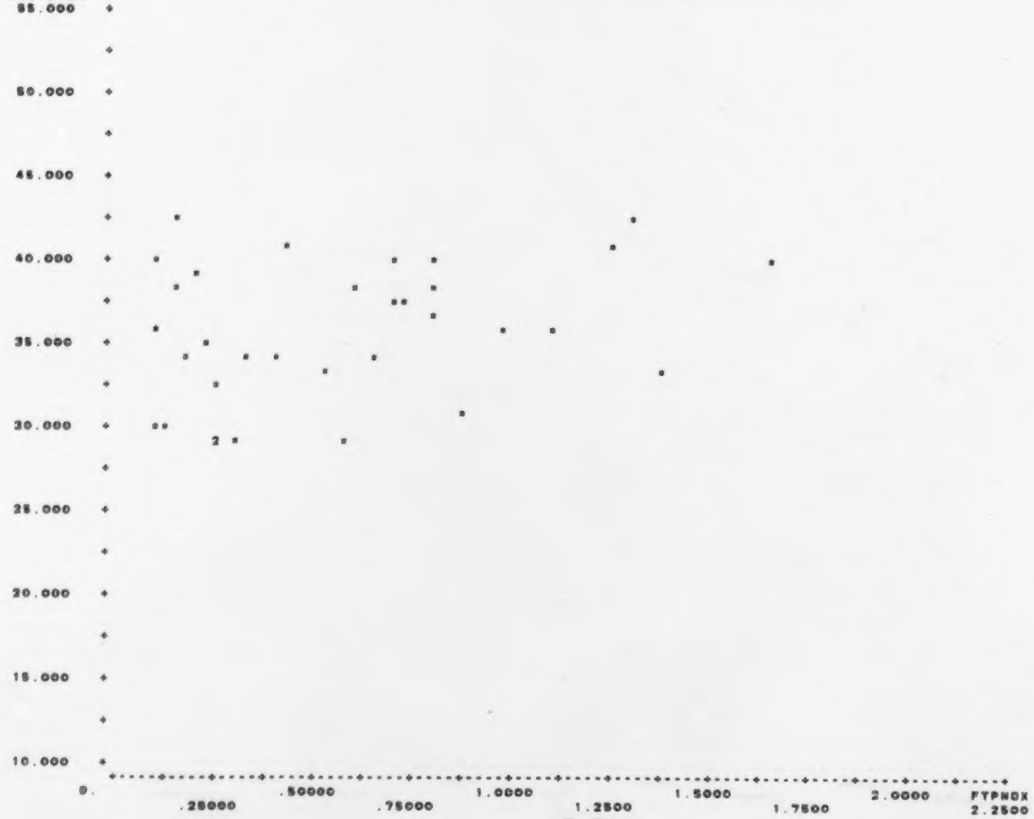

Appendix 10

Plots of Ton-Miles per Gallon versus Emissions by Emission Control System and Transmission Type

Two variable linear regression plots of Ton-Miles per Gallon for Urban Fuel Economy (UMPGETW) and Combined Fuel Economy (CMPGETW), each plotted against FTPHC, FTPCO, and FTPNOX.

Data from EPA/CERT Data Base, restricted to non-durability, non-Diesel vehicles of test active years 1980 and 1981 was used.

Stratification by emission control system and by transmission type (CA, CM, and LA). (See Section IV. H.)

Only graphs containing at least 12 points are included.

```
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          N= 50 OUT OF 63  67.UMPGTETW VS. 1.FTPHC
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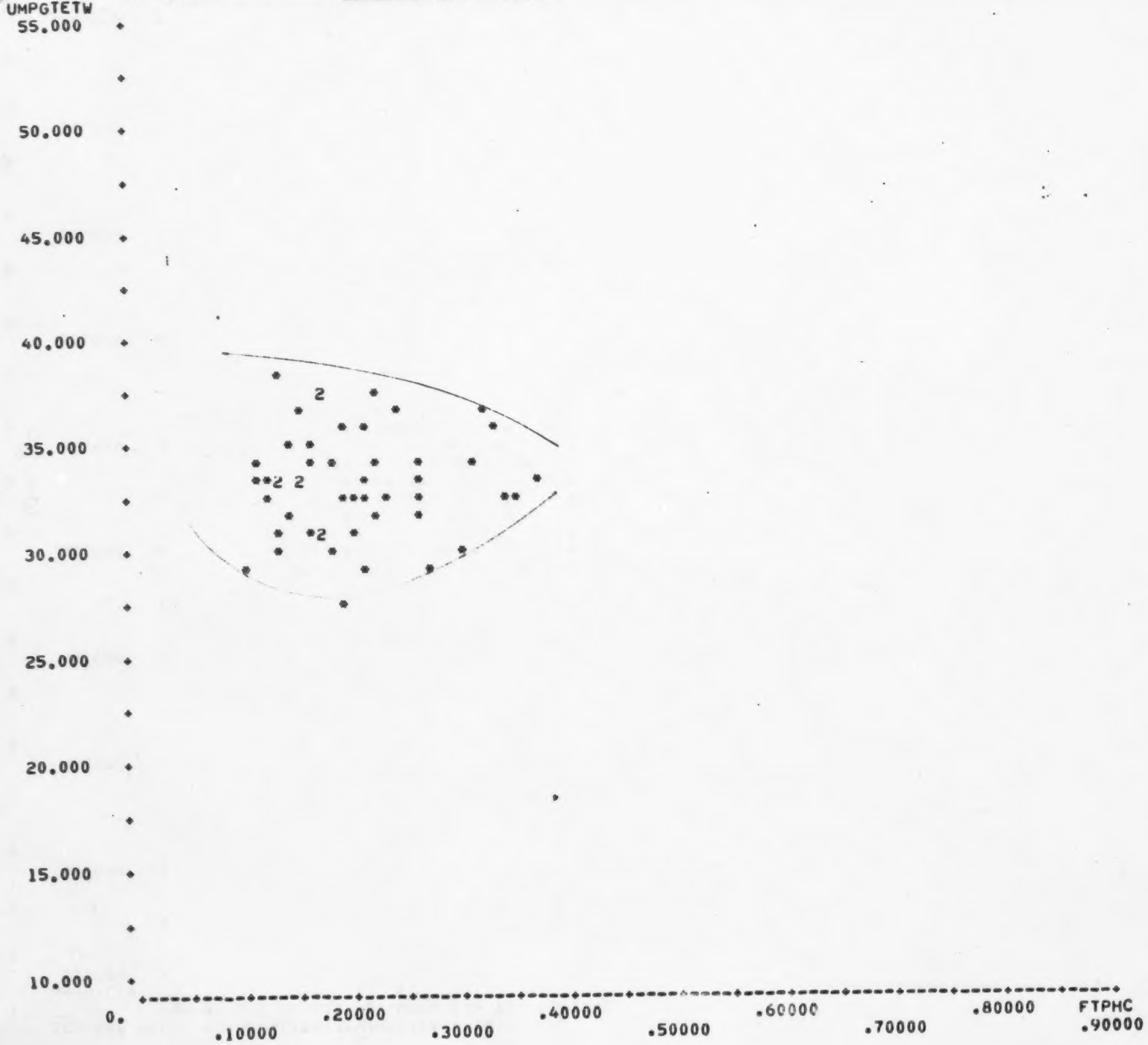

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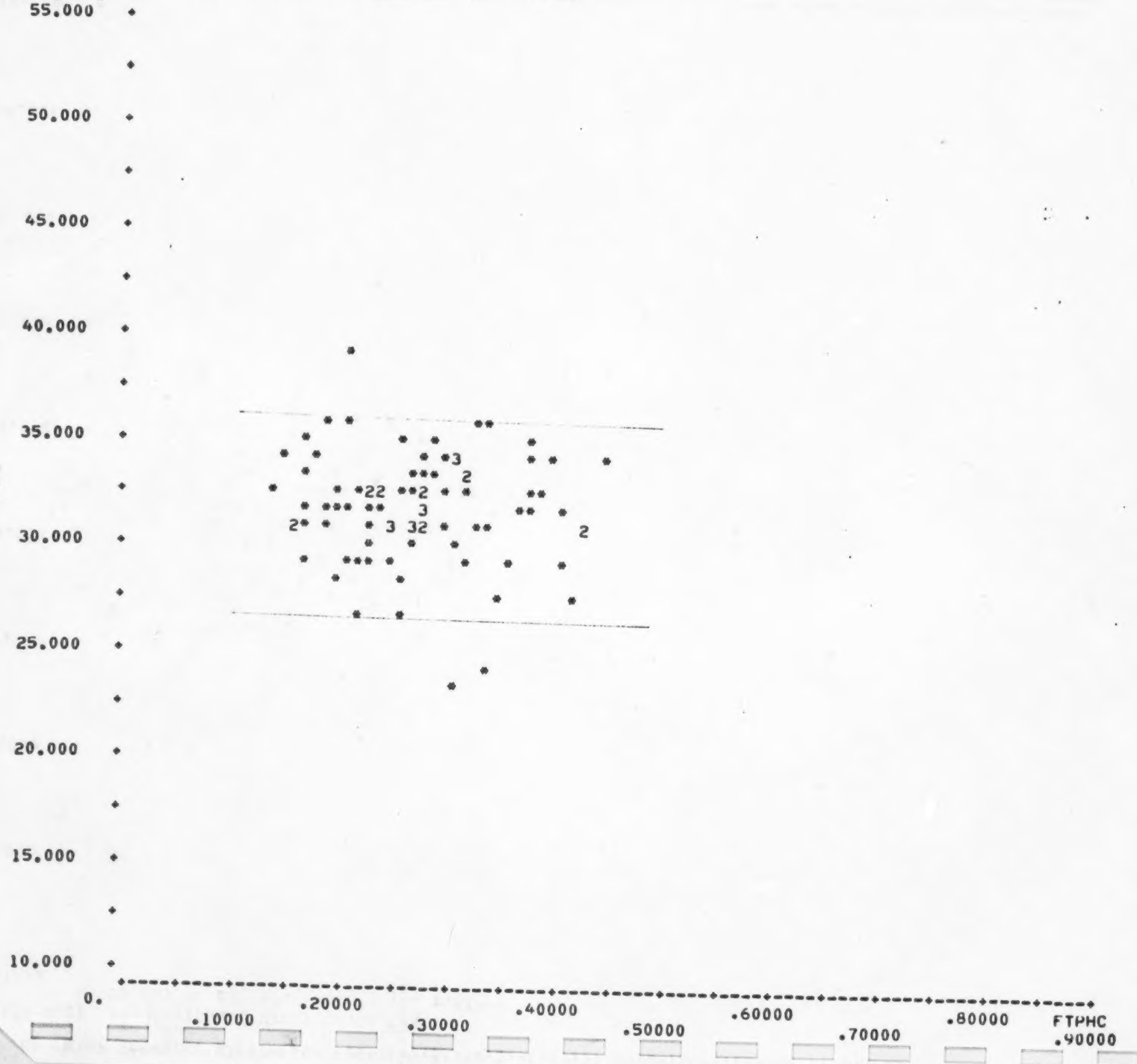
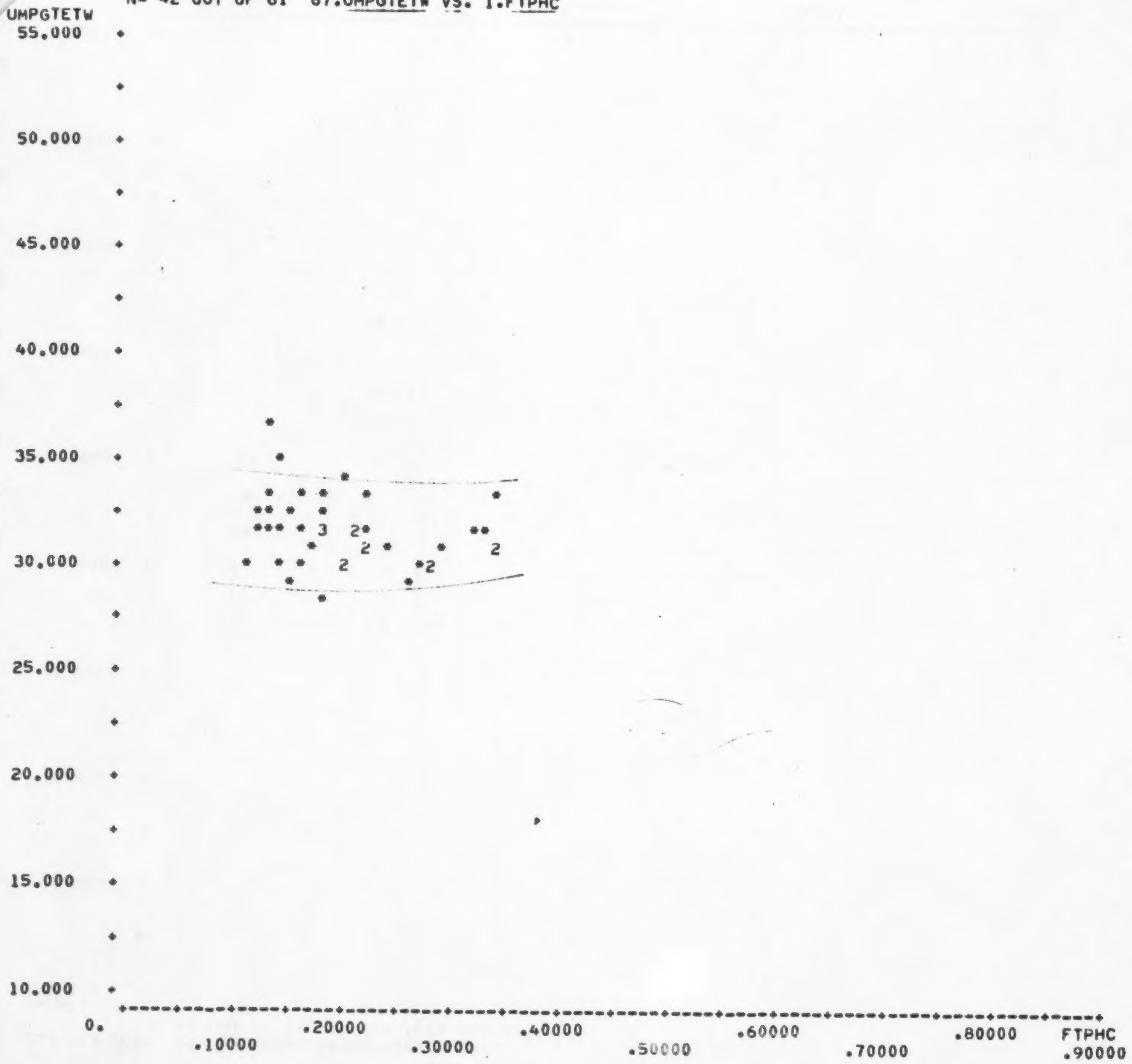
N= 89 OUT OF 125 67.UMPGTETW VS. 1.FTPHC



ATTER PLOT <4> SYS1TU8:4PV(RN:(CA,CA,CA)
N= 42 OUT OF 61 67.UMPGTETW VS. 1.FTPHC



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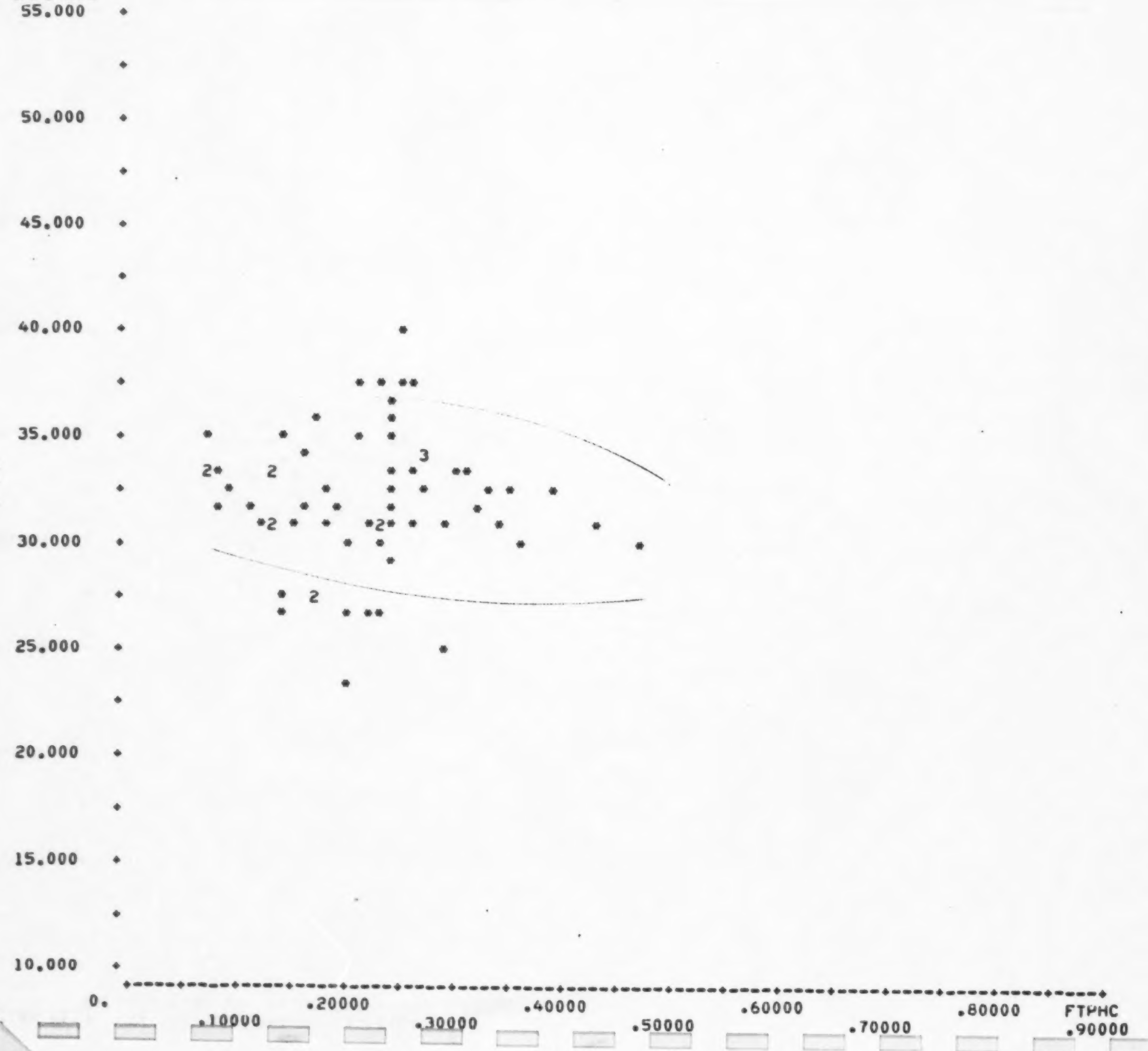
N= 65 OUT OF 79 67.UMPGTETW VS. 1.FTPHC



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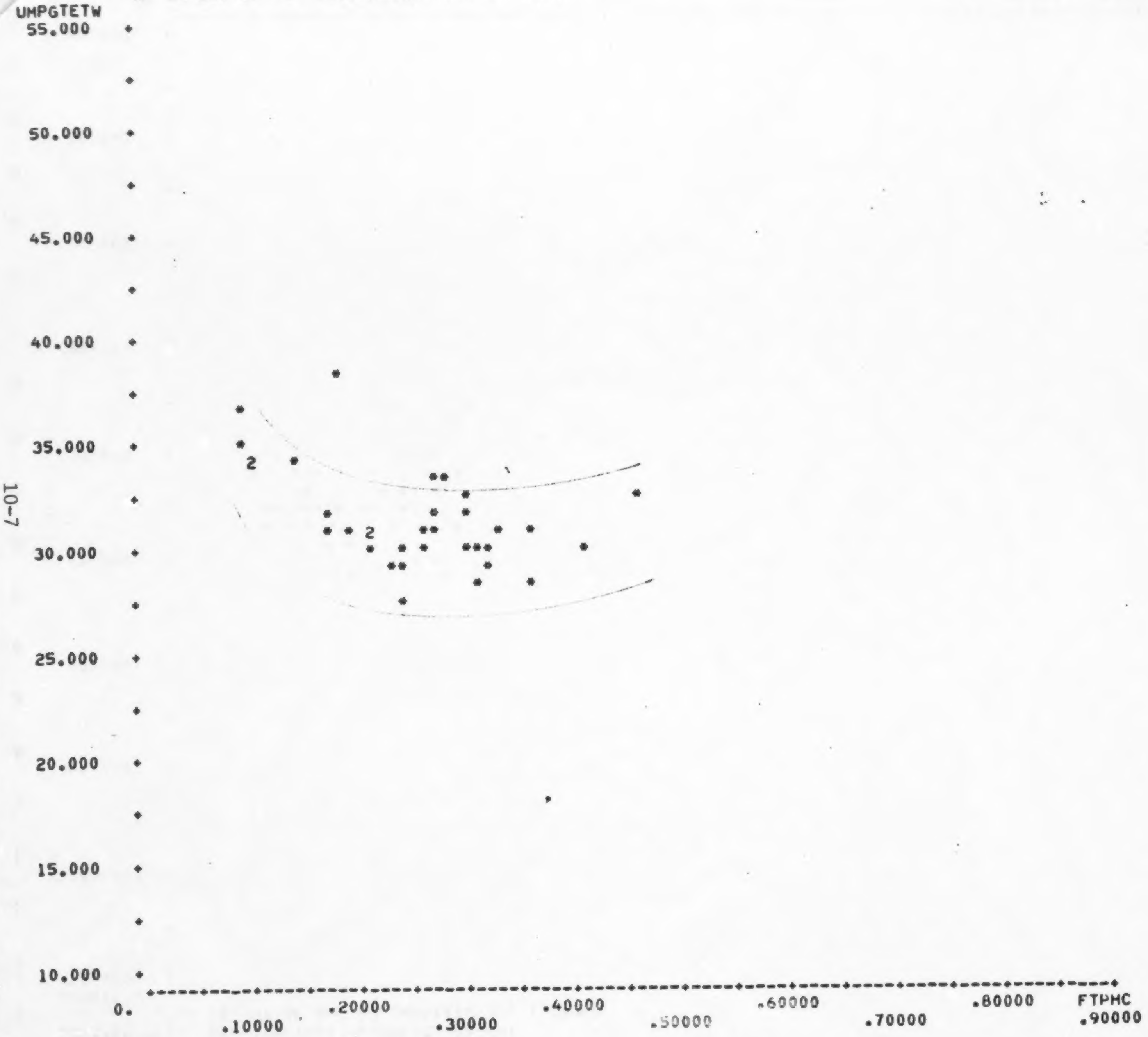
N= 34 OUT OF 41 67.UMPGTETW VS. 1.FTPHC



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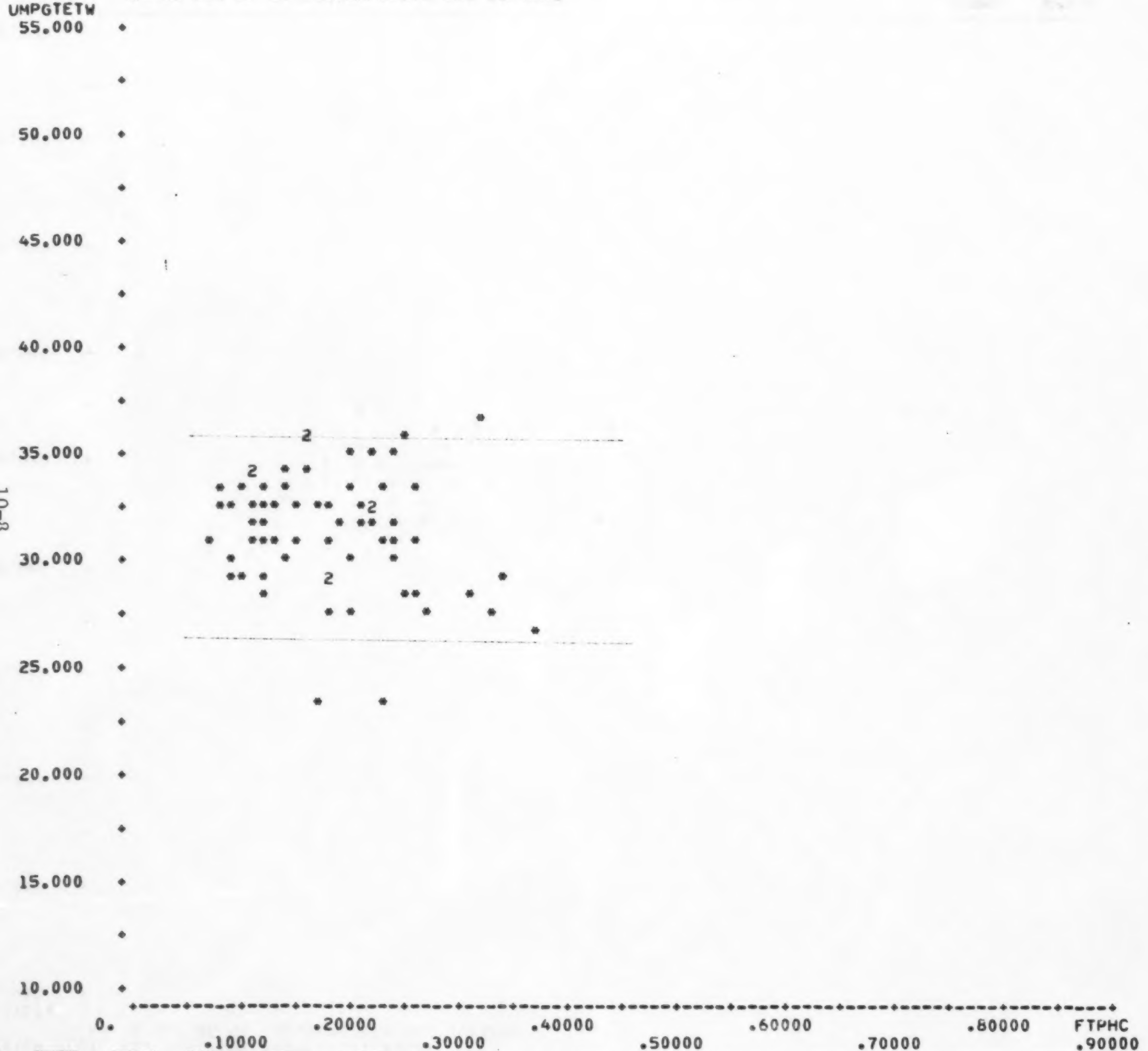
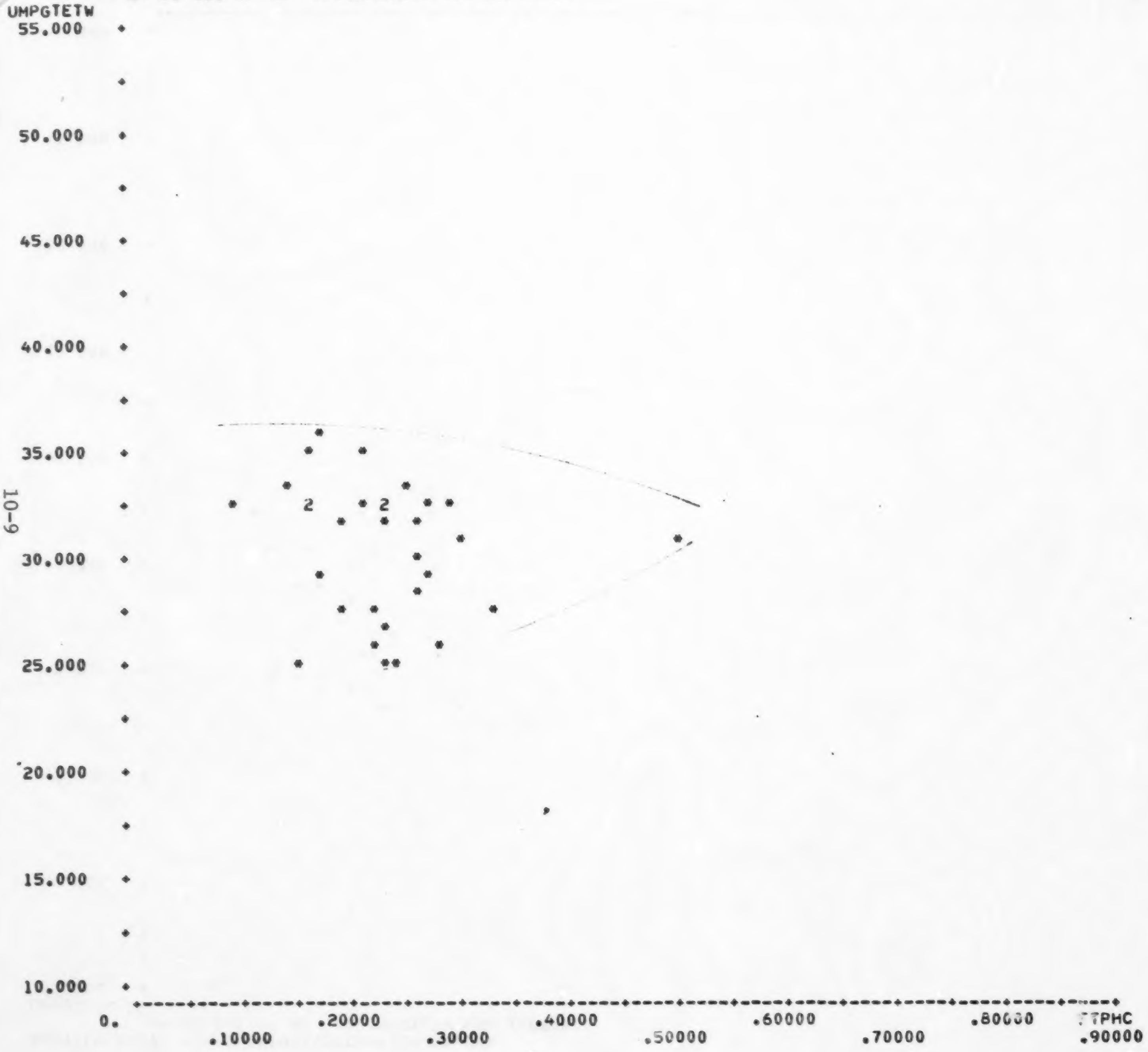
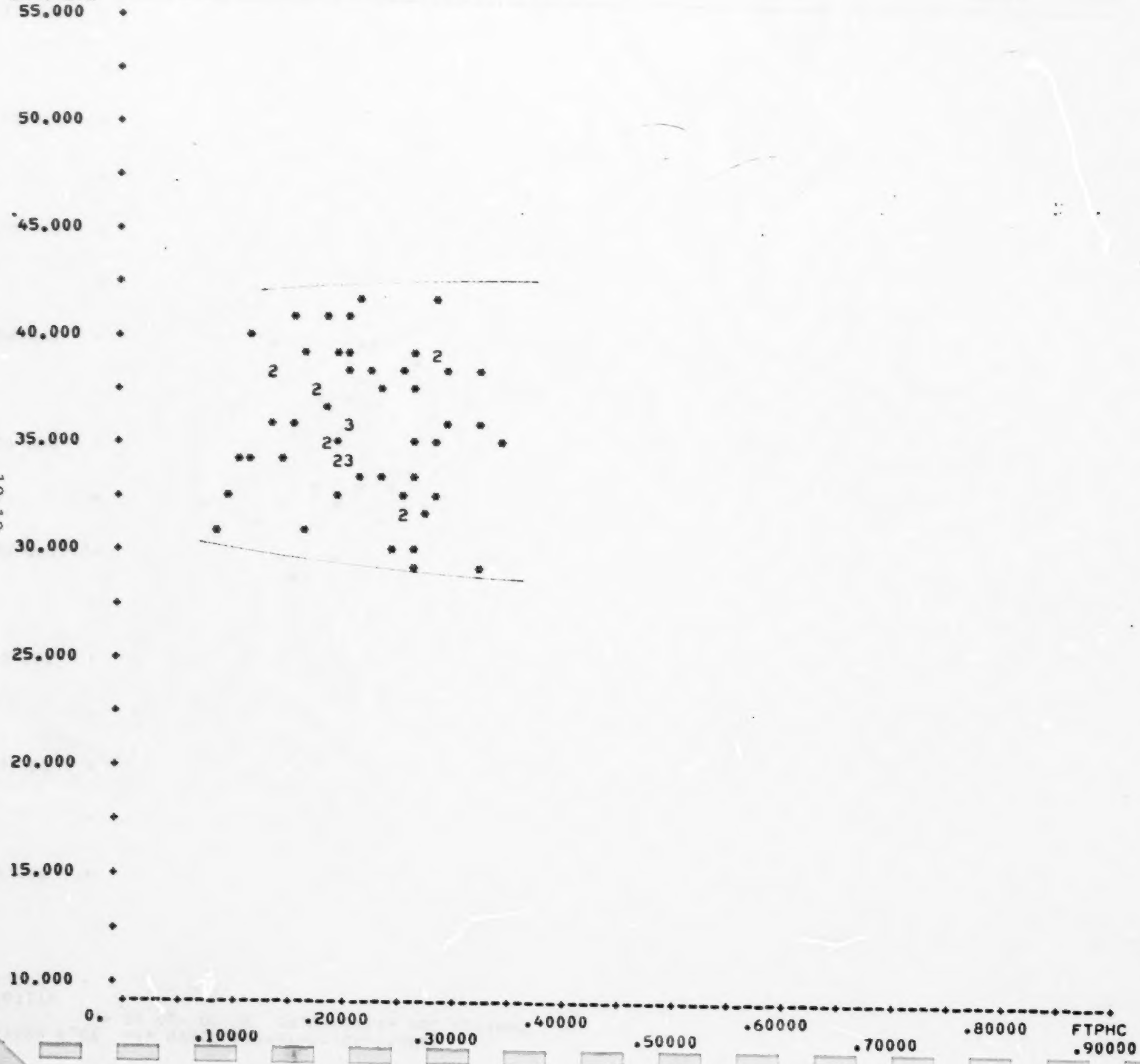
N= 65 OUT OF 89 67.UMPGTETW VS. 1.FTPHC



ATTER PLOT <8> SYS1T08:8*VTRN:(CA,CA,CA)
N= 31 OUT OF 42 67.UMPGTETW VS. 1.FTPHC



SCATTER PLOT <9> SYS1T08:1*VTHN:(CM,CM,CM)
N= 61 OUT OF 85 67.UMPGTETW VS. 1.FTPHC



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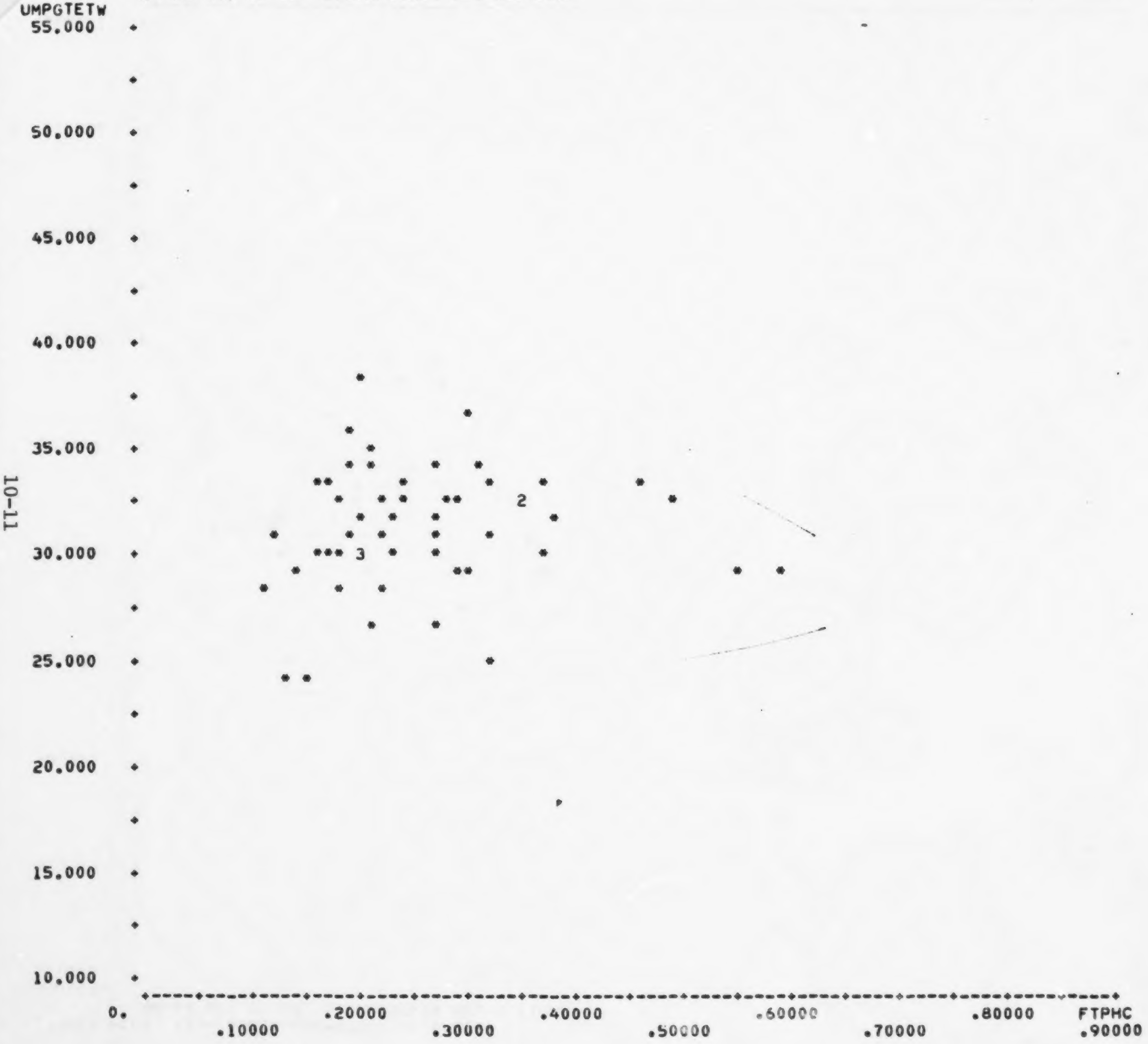

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SCATTER PLOT  <12> SYSITU8:4*VTRN:(CM,CM,CM)
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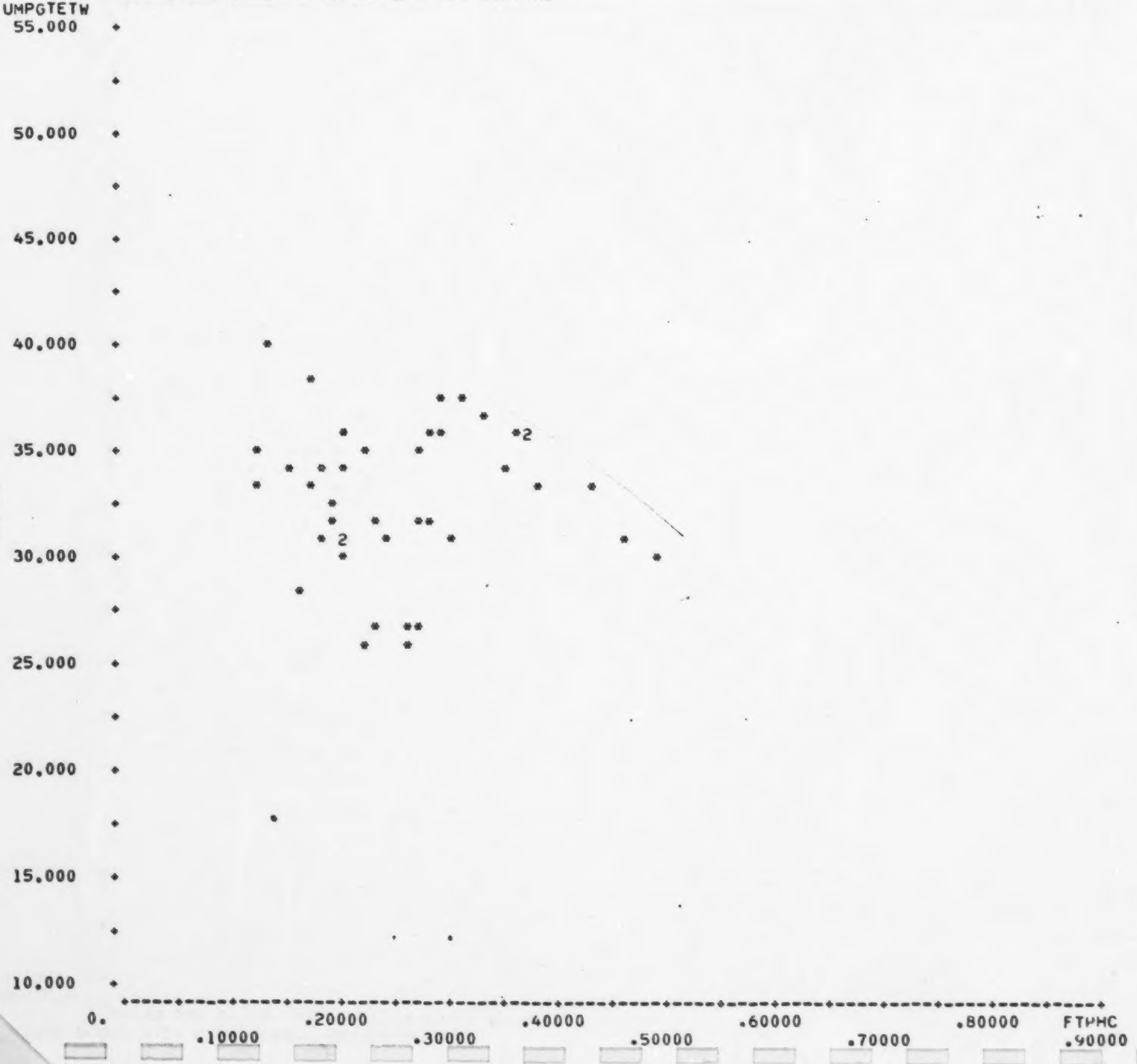

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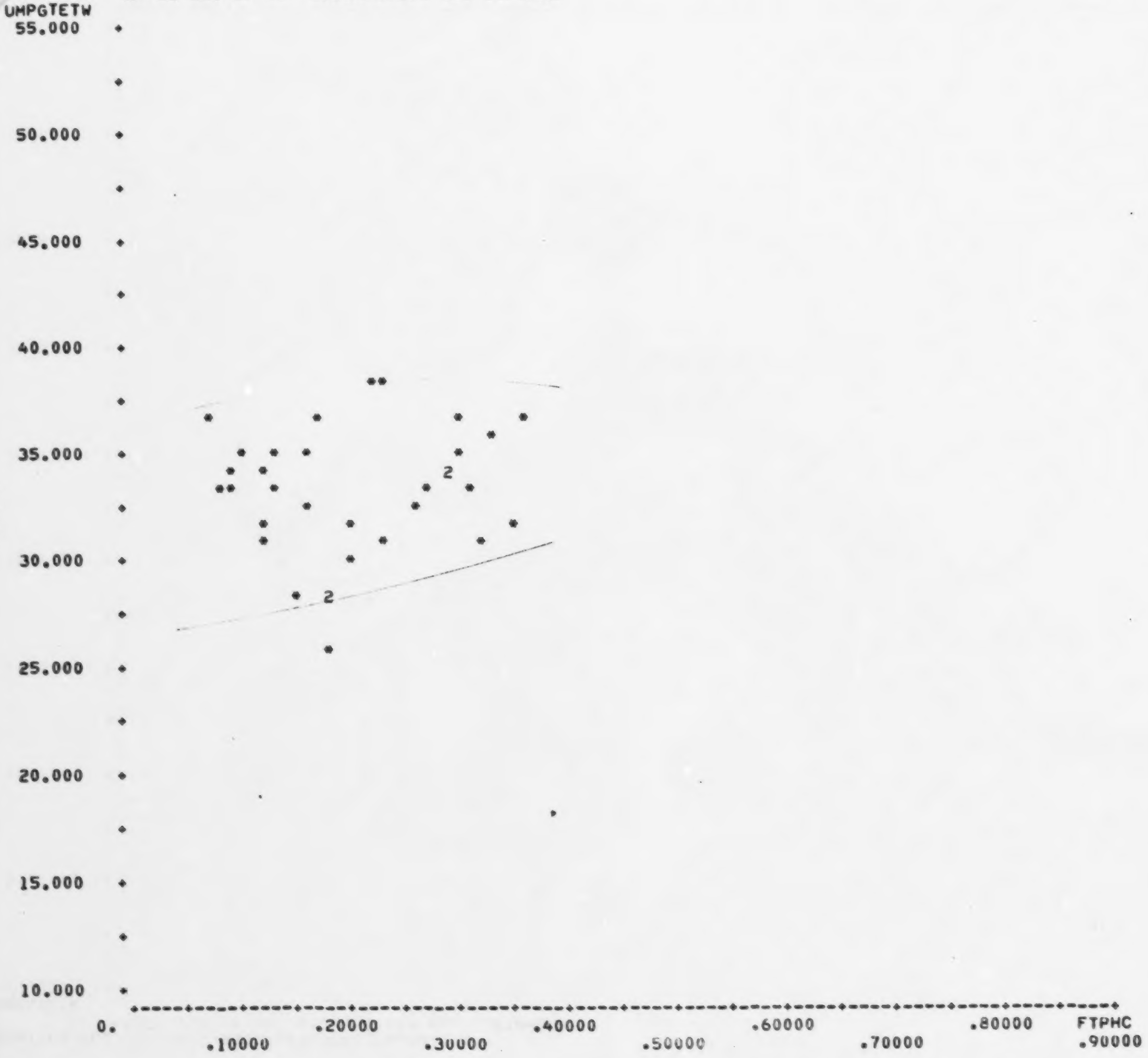
N= 33 OUT OF 46 67.UMPGTETW VS. 1.FTPHC



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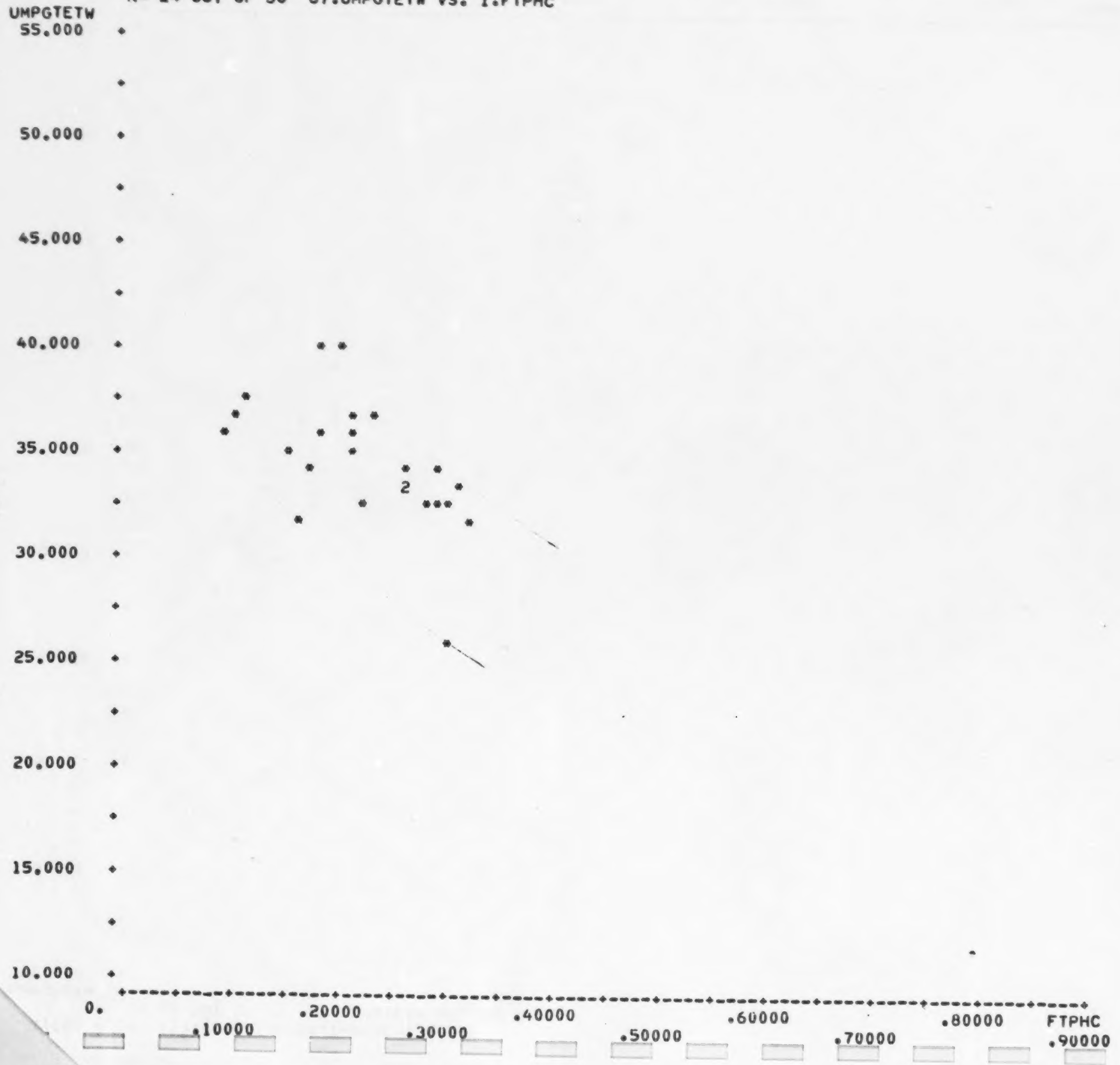

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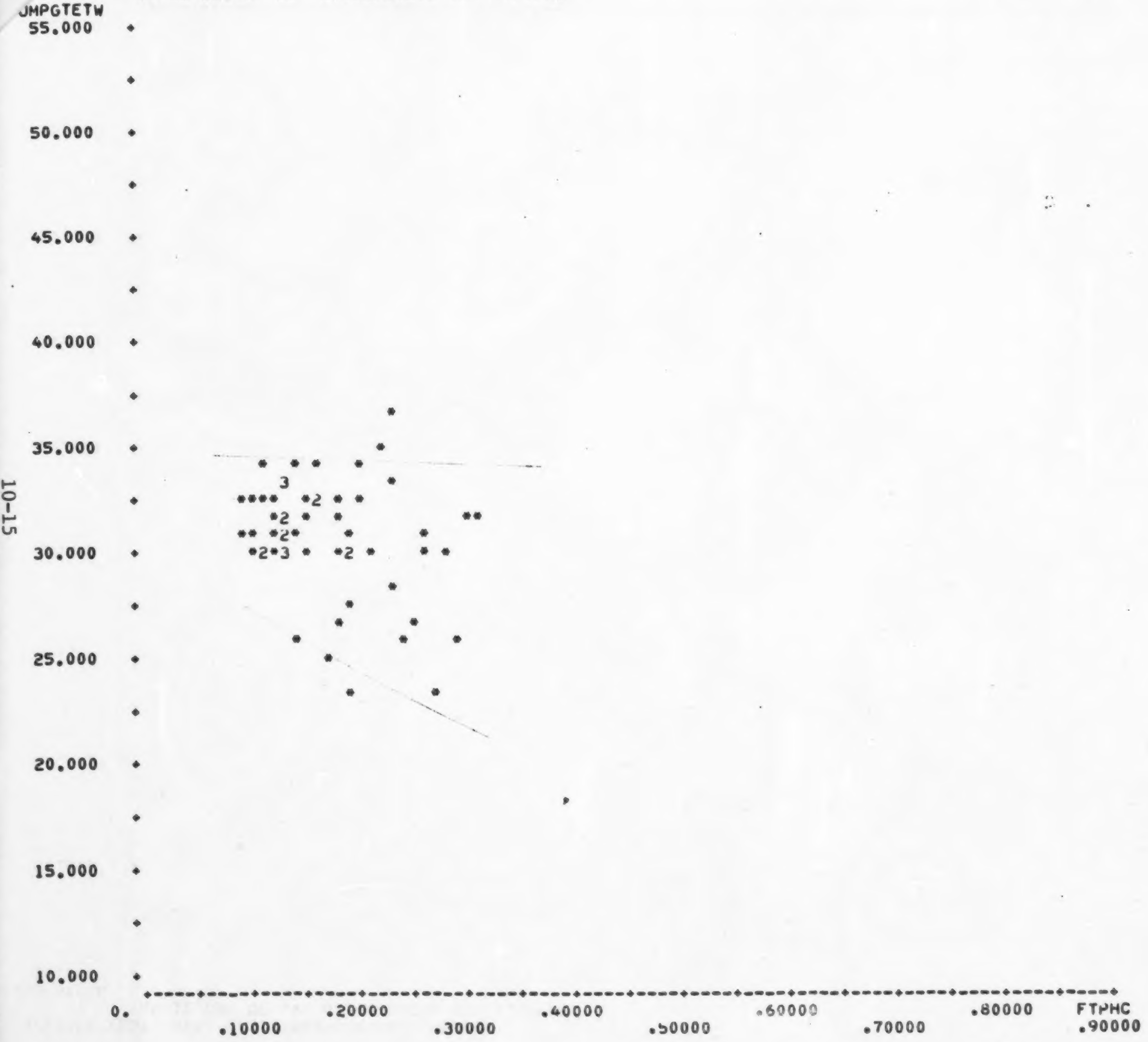

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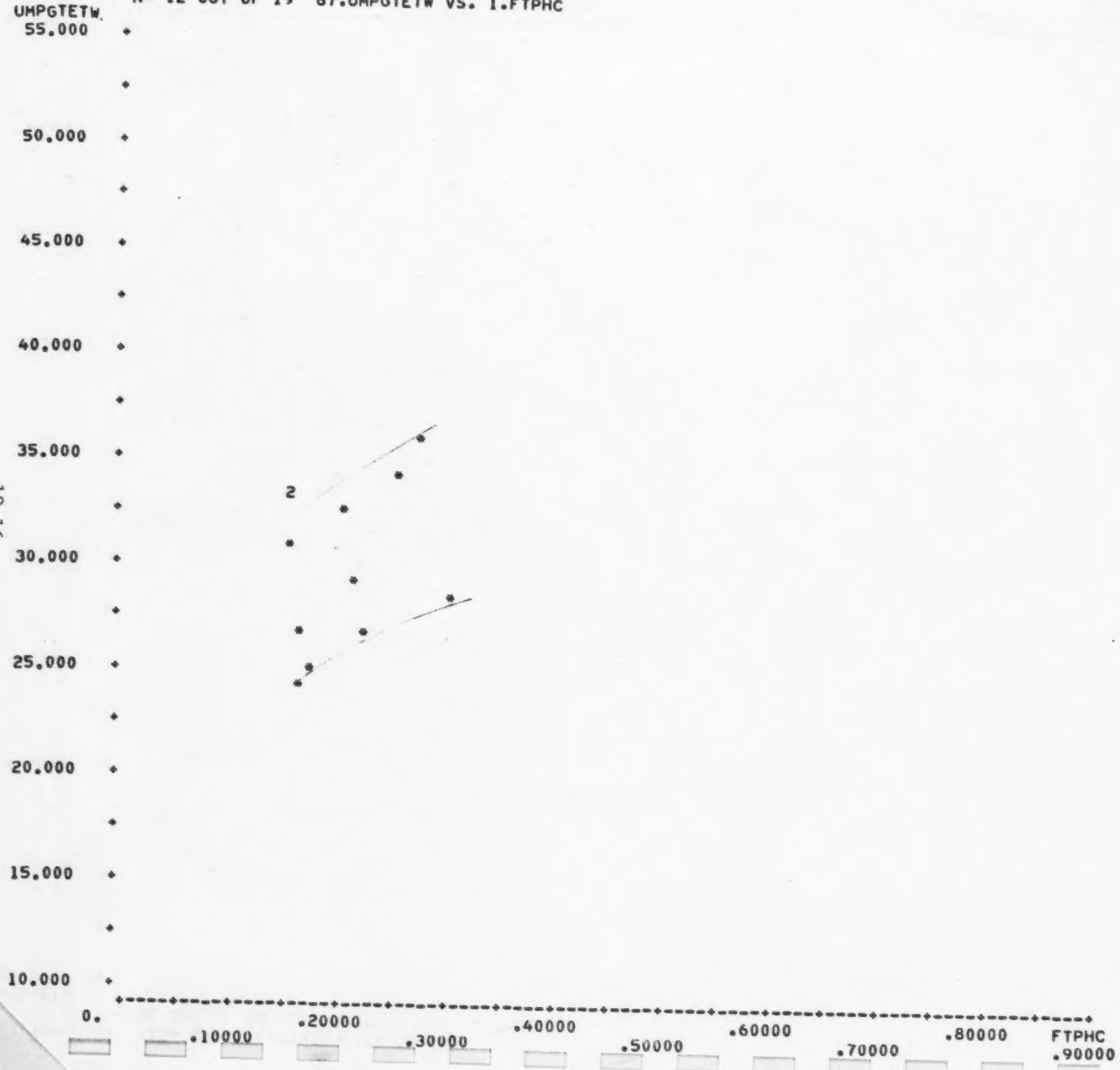

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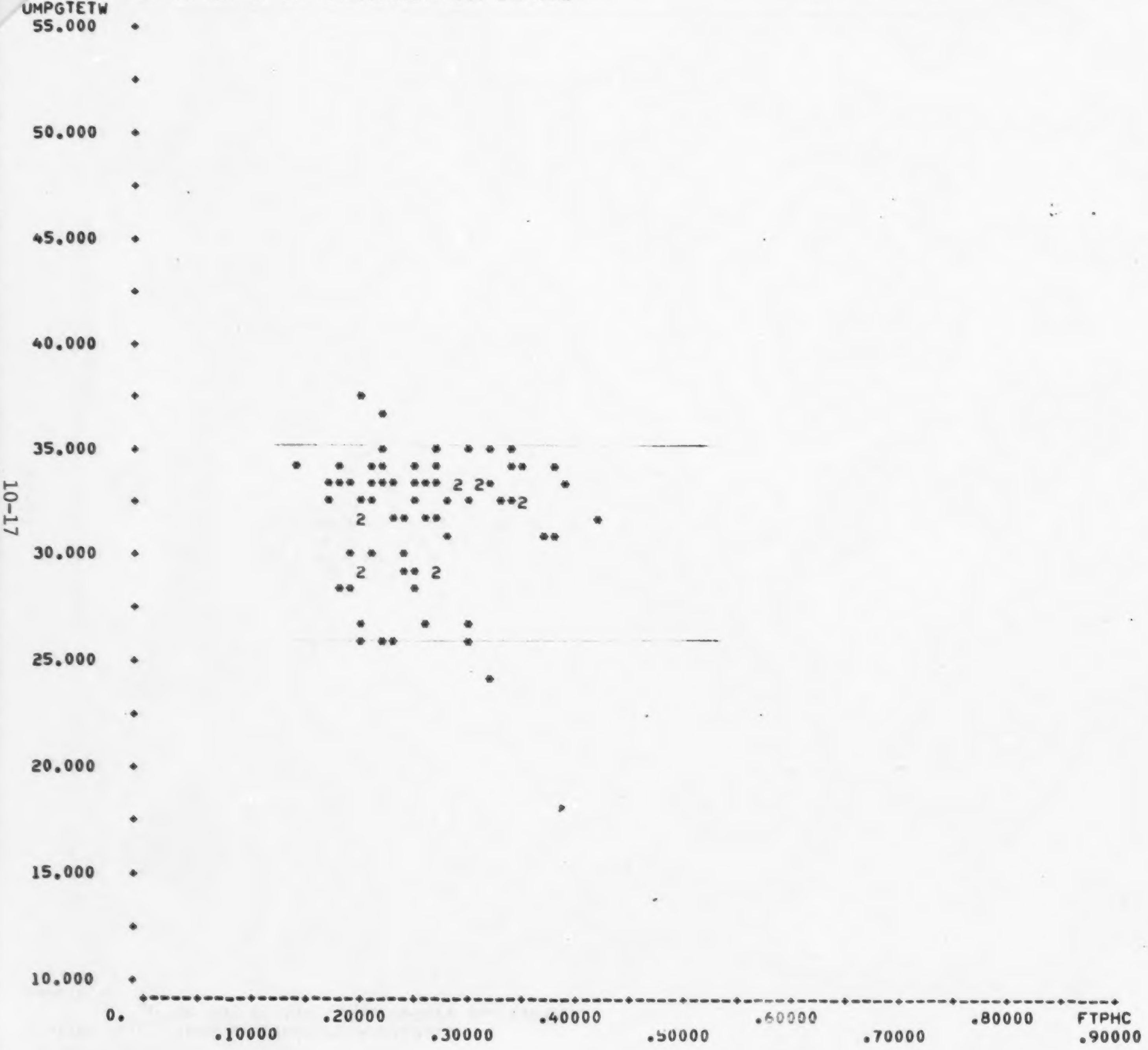

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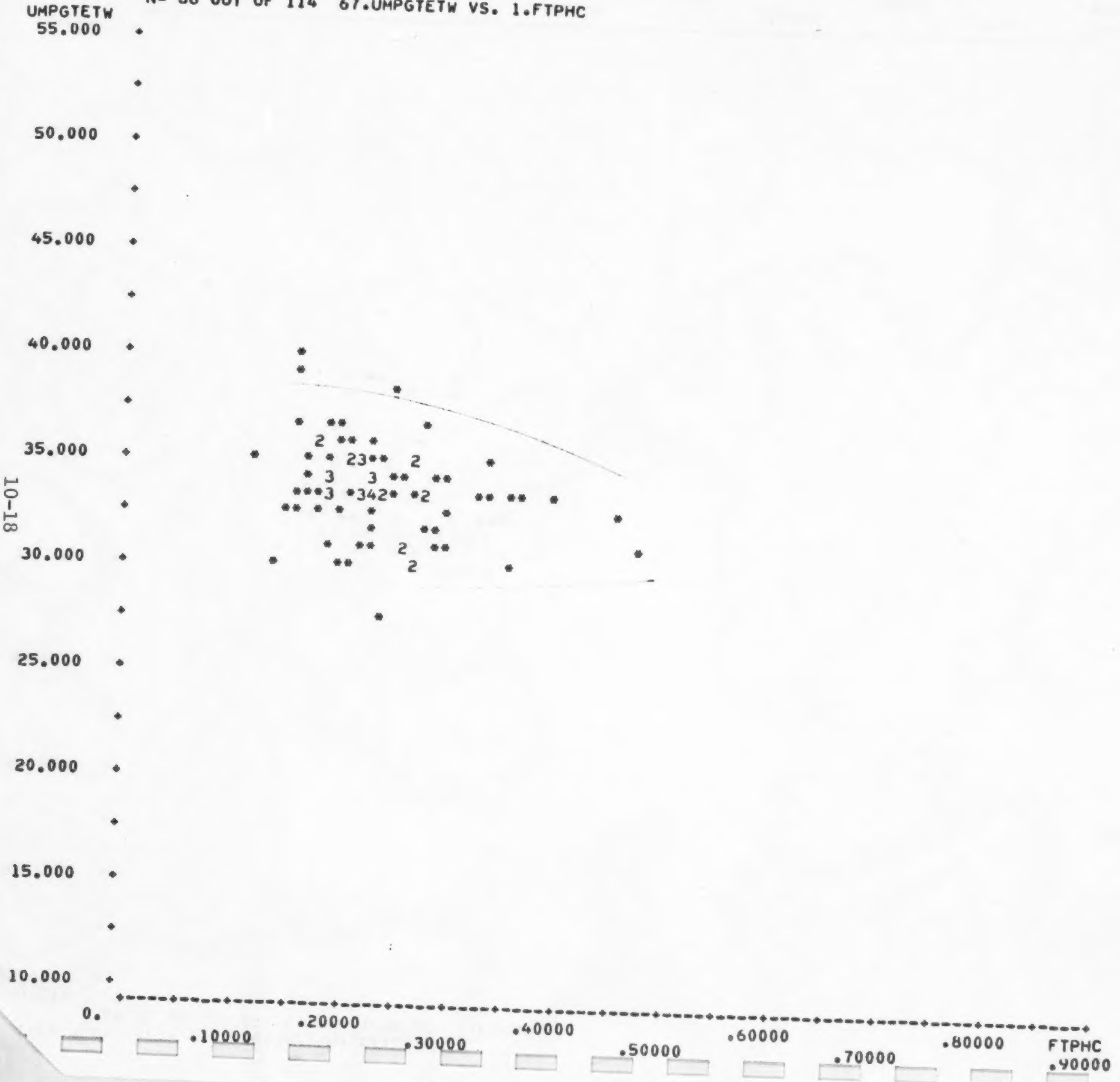

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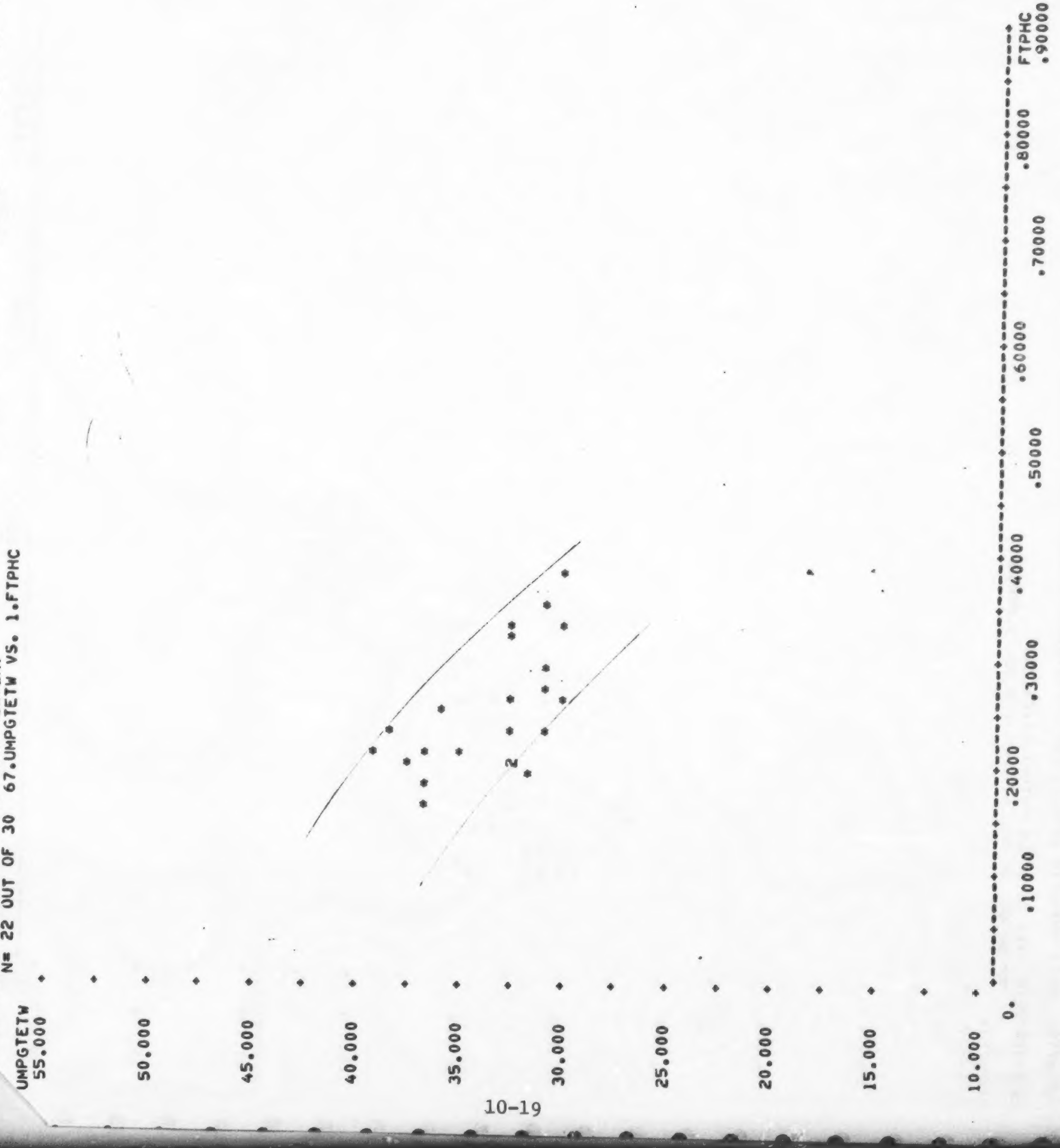

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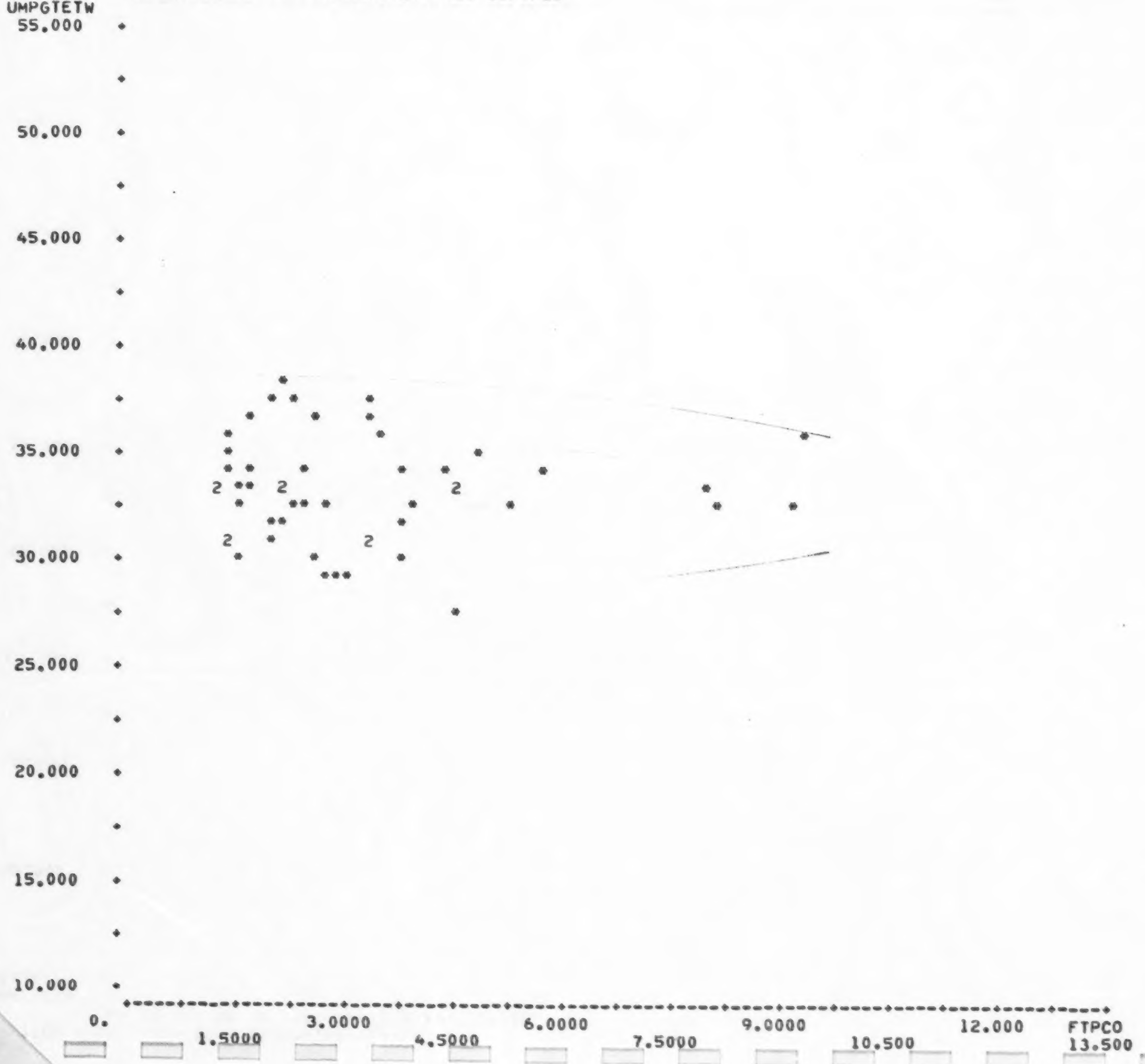

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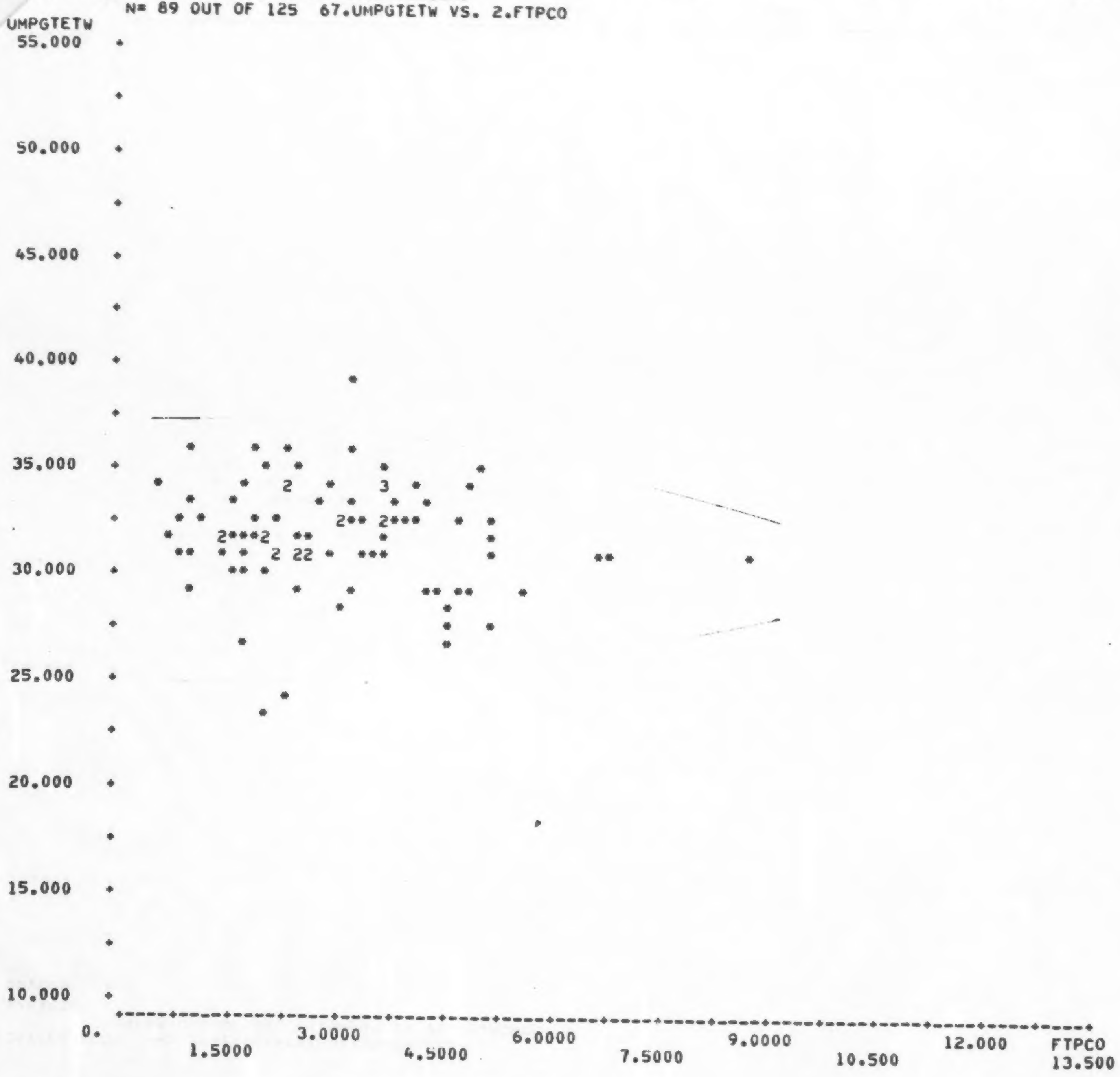

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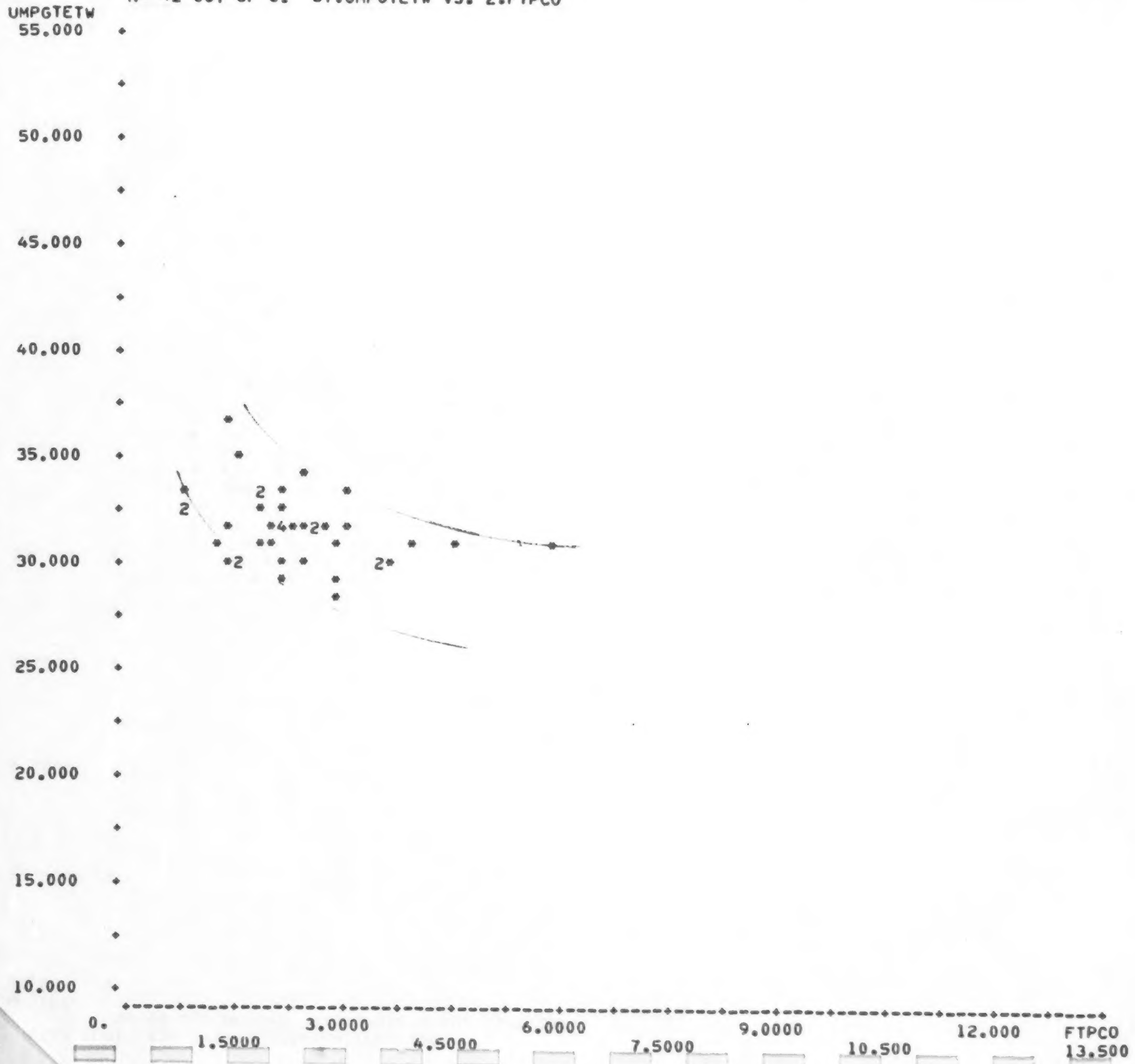

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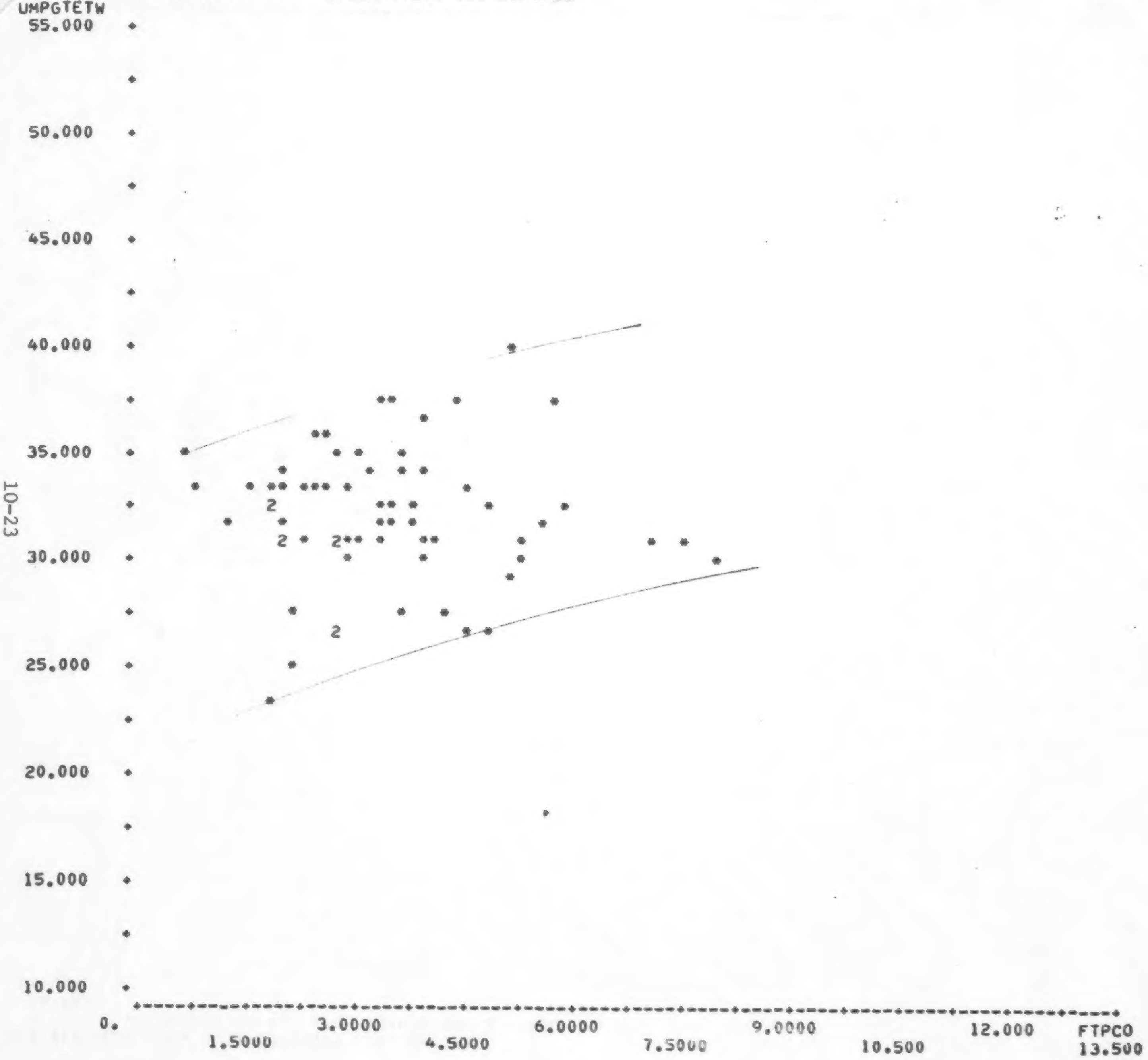

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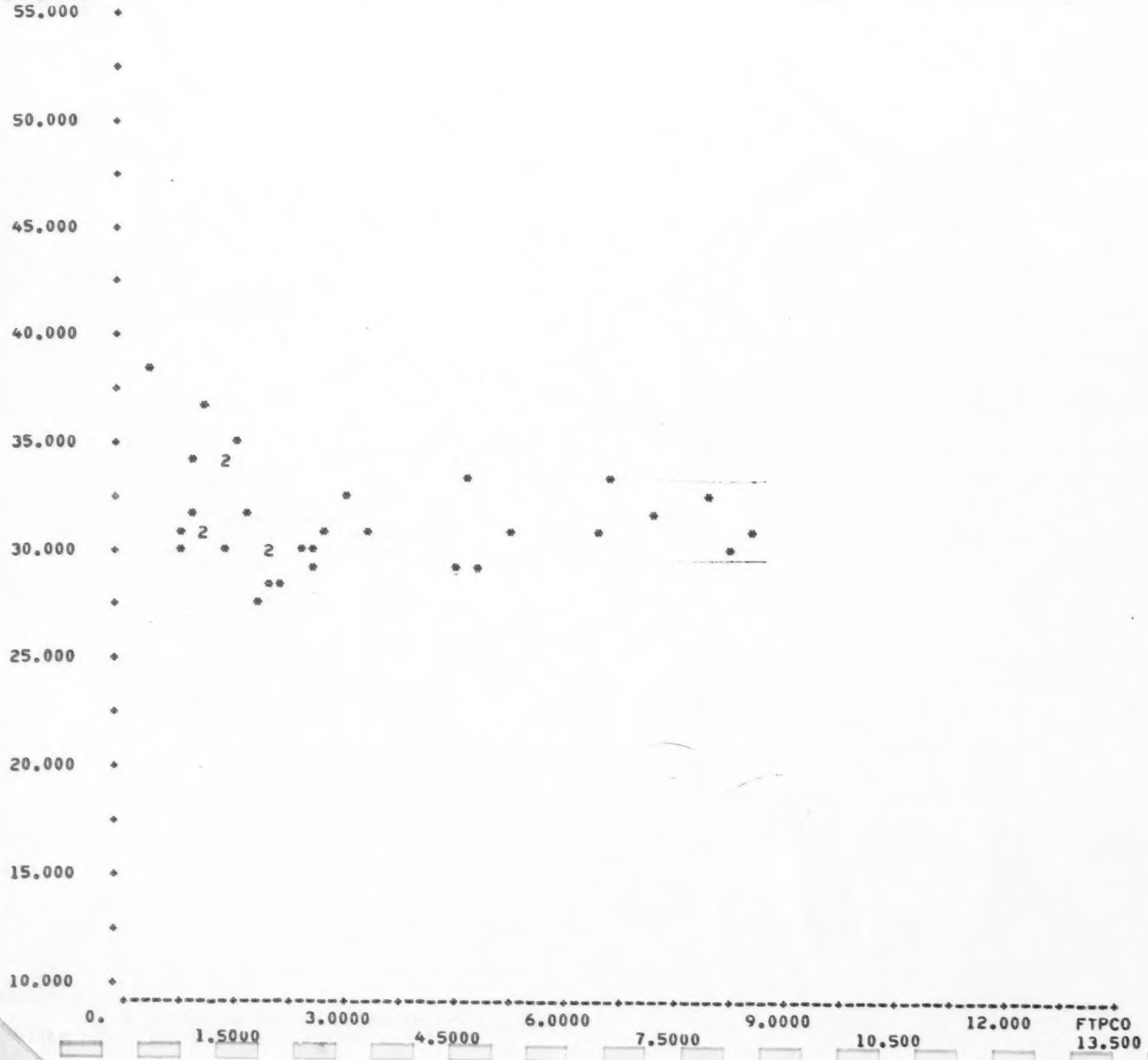

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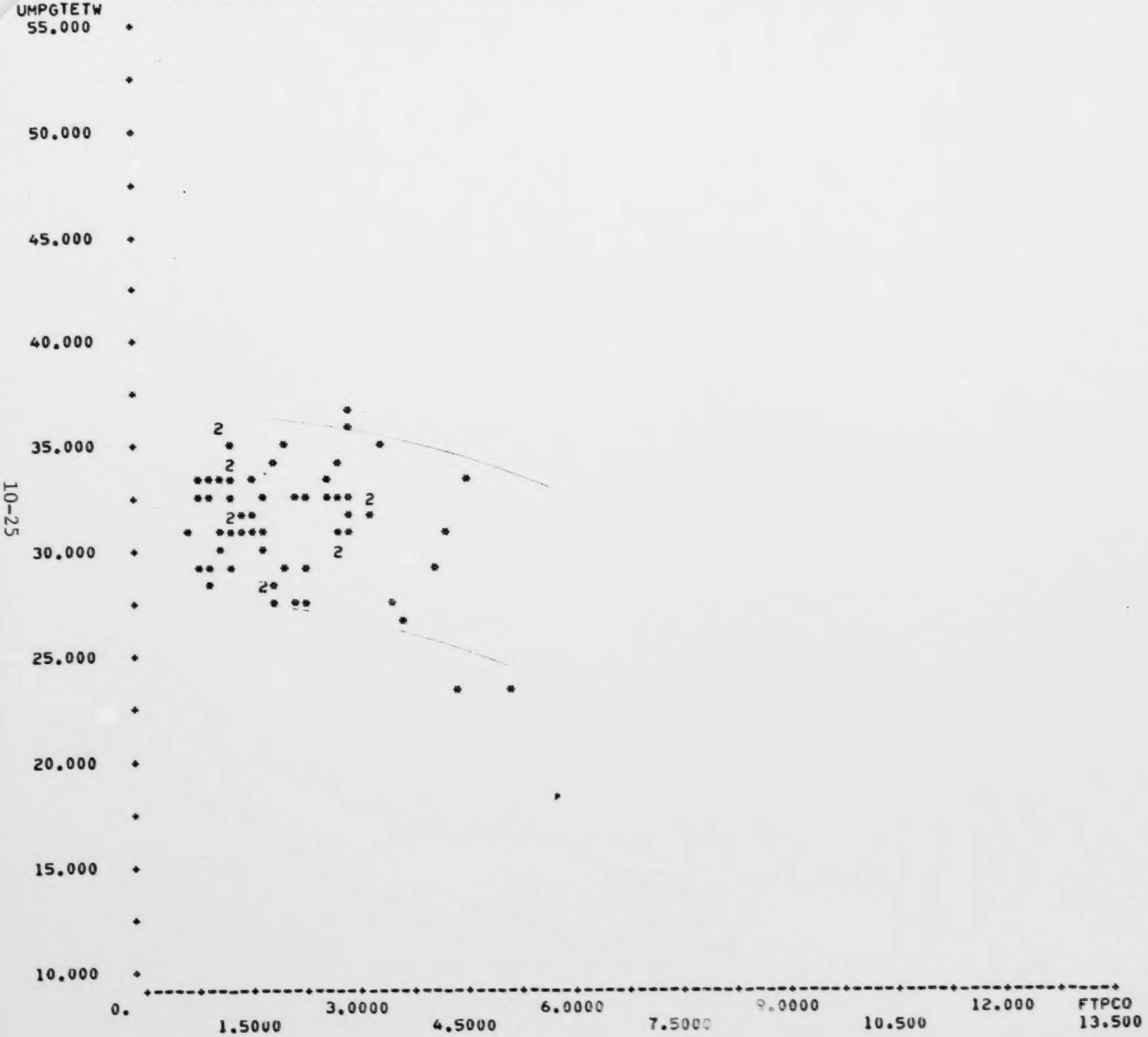

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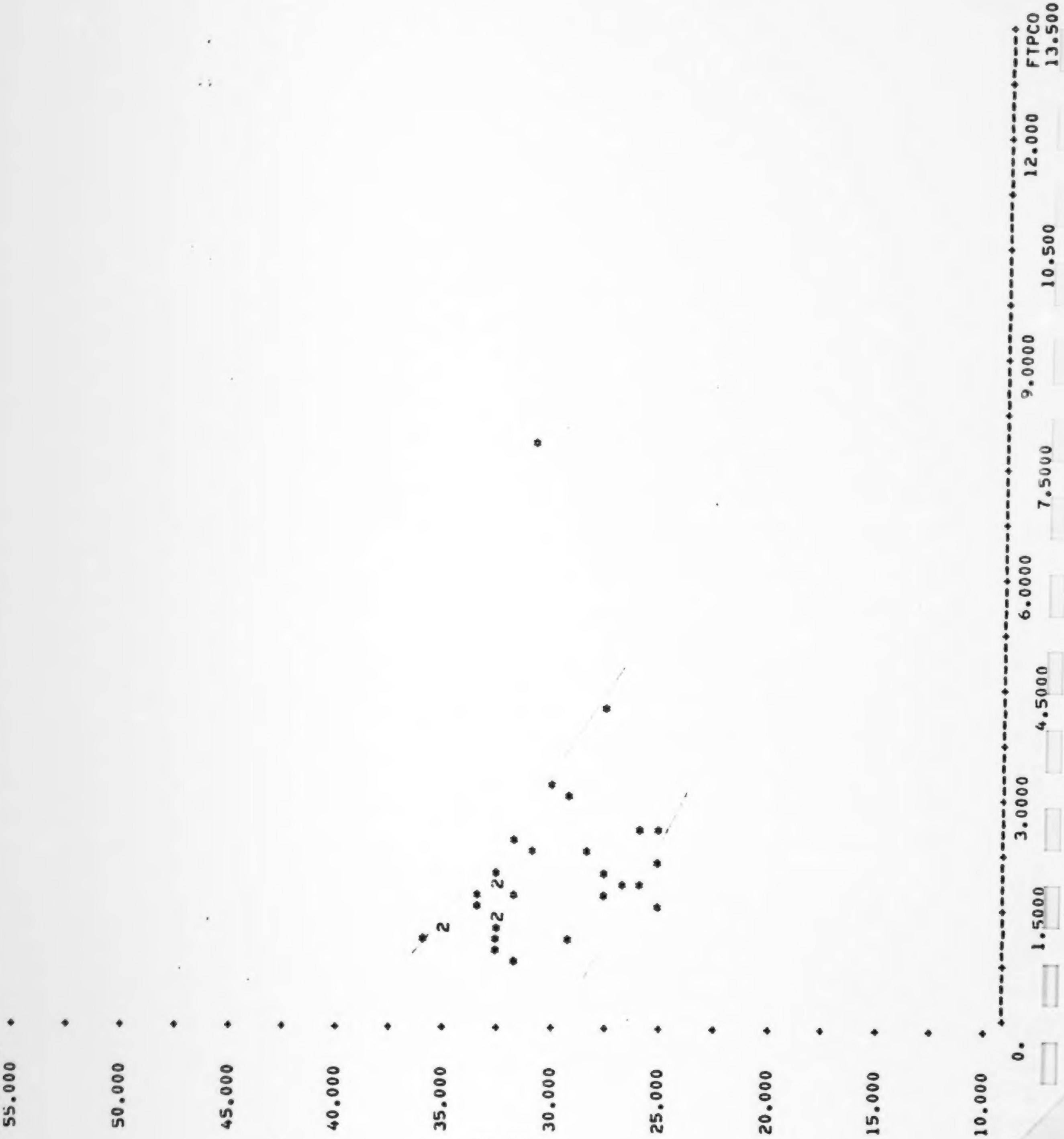

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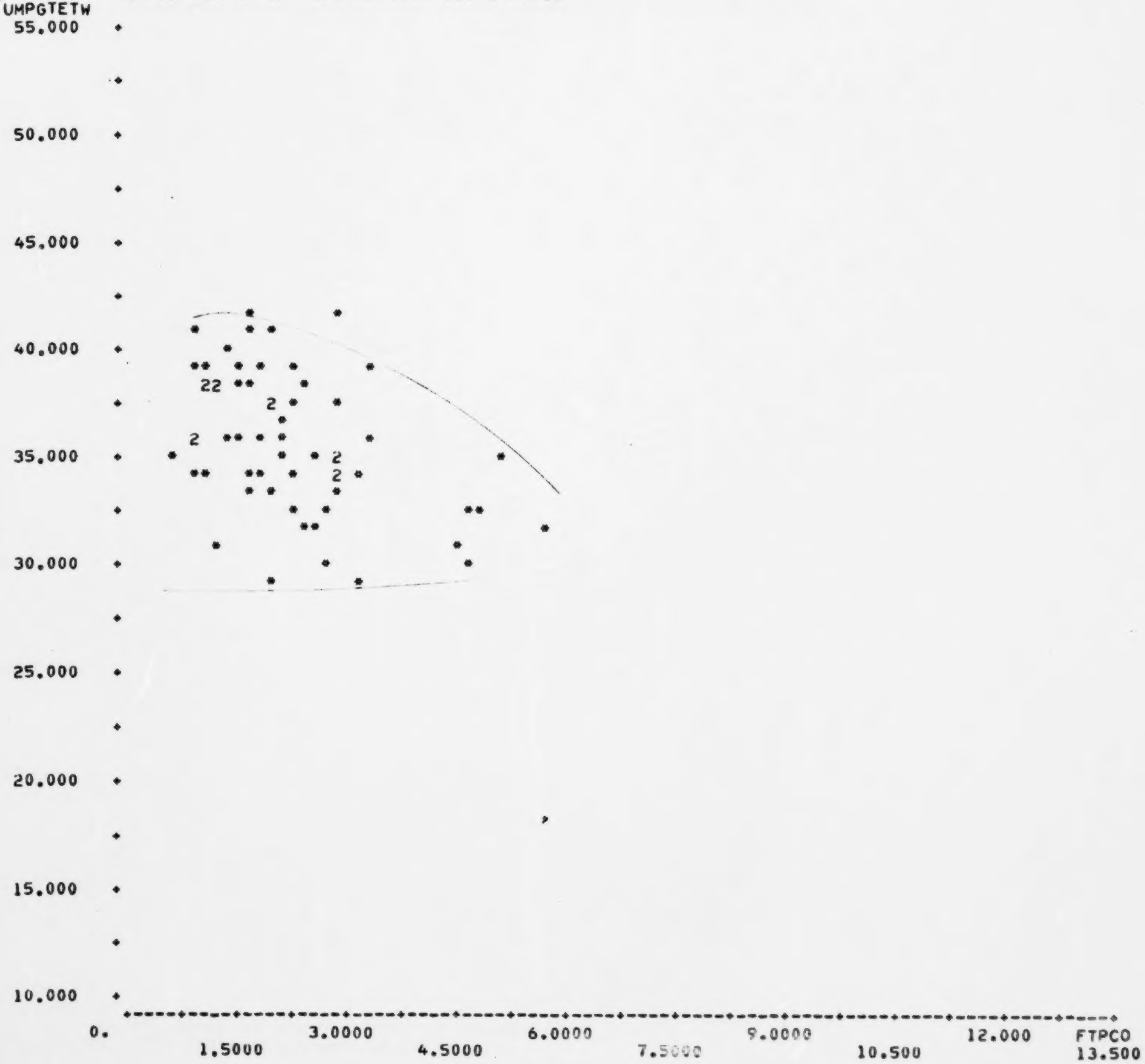

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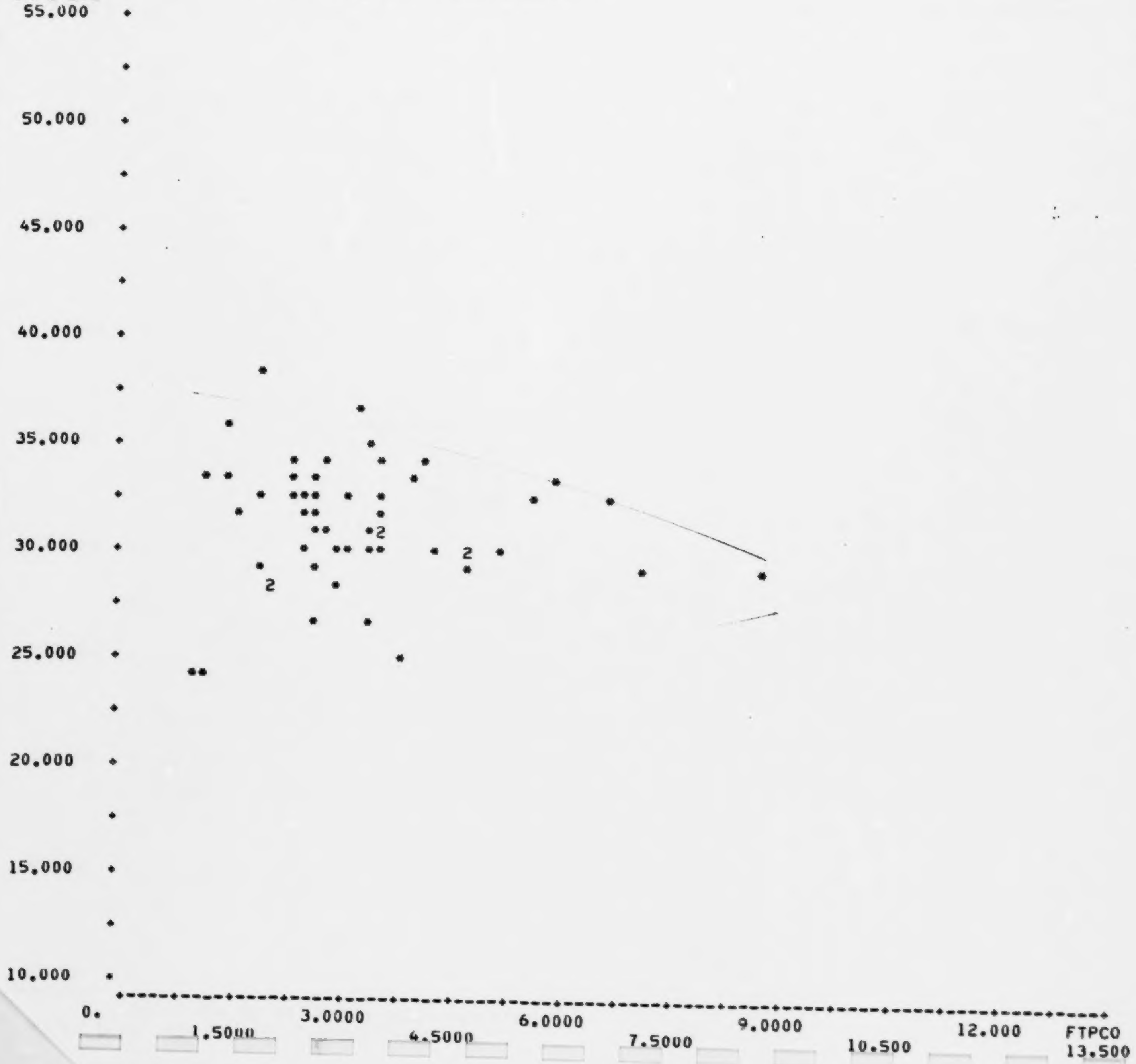

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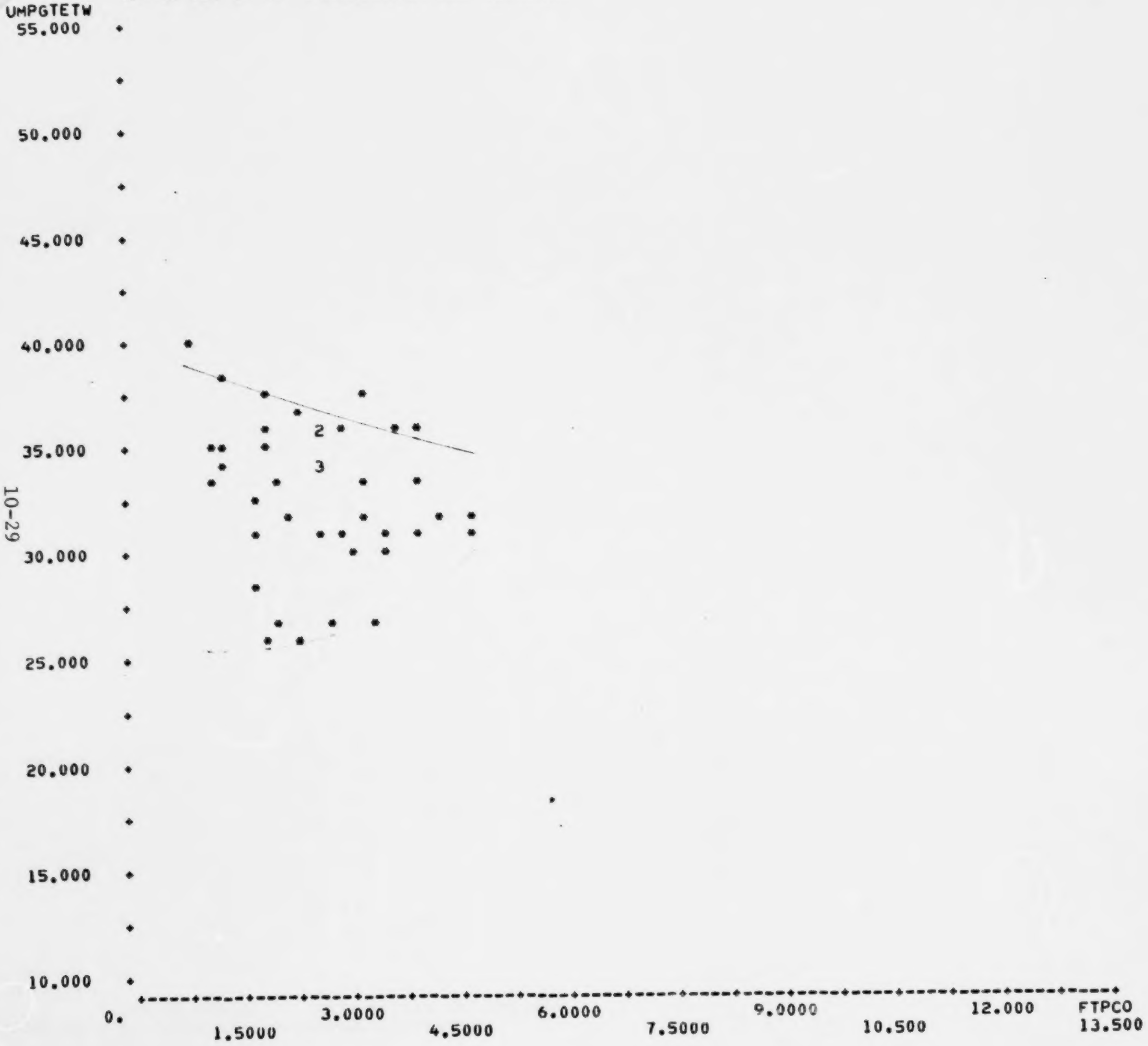

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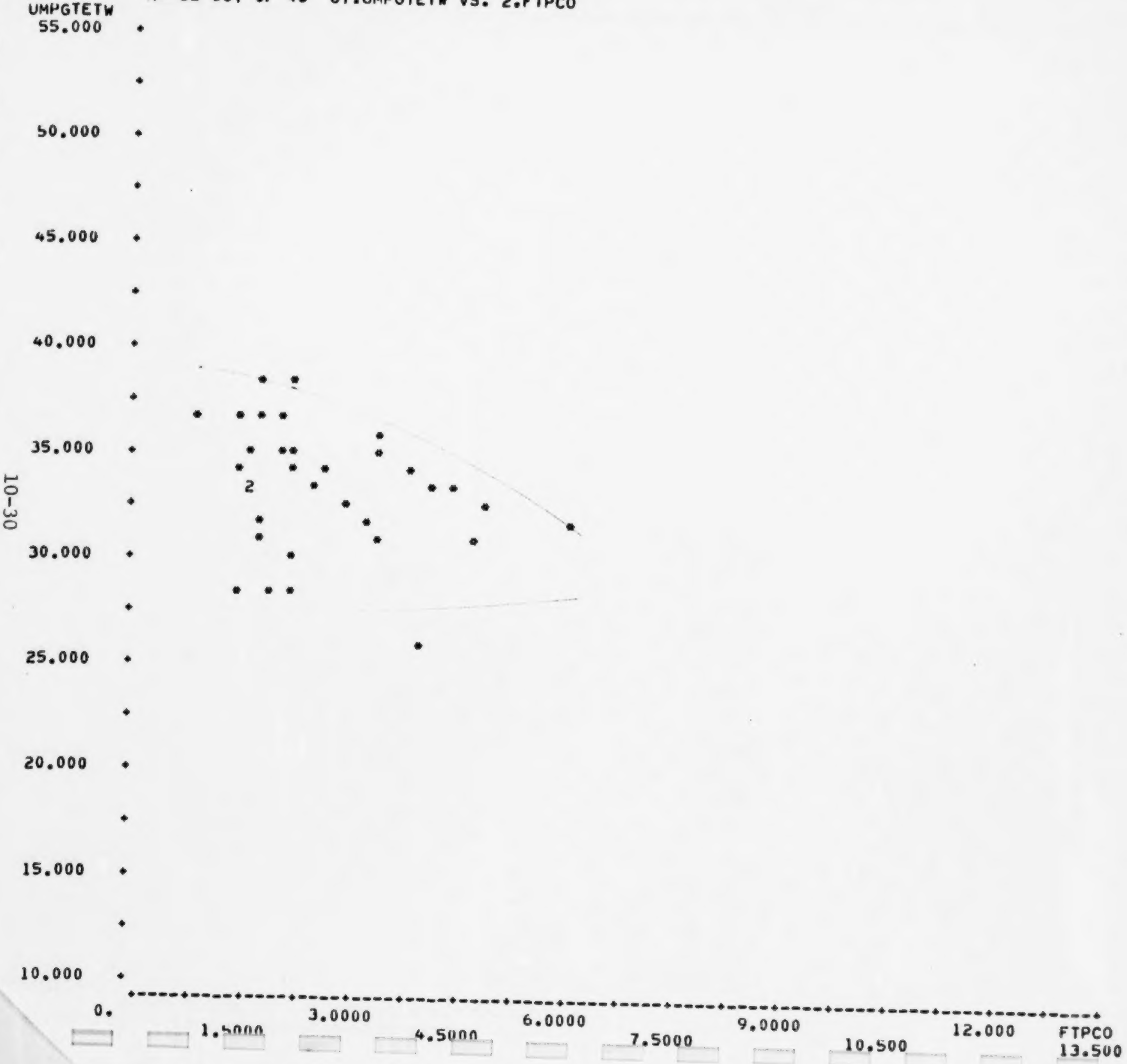

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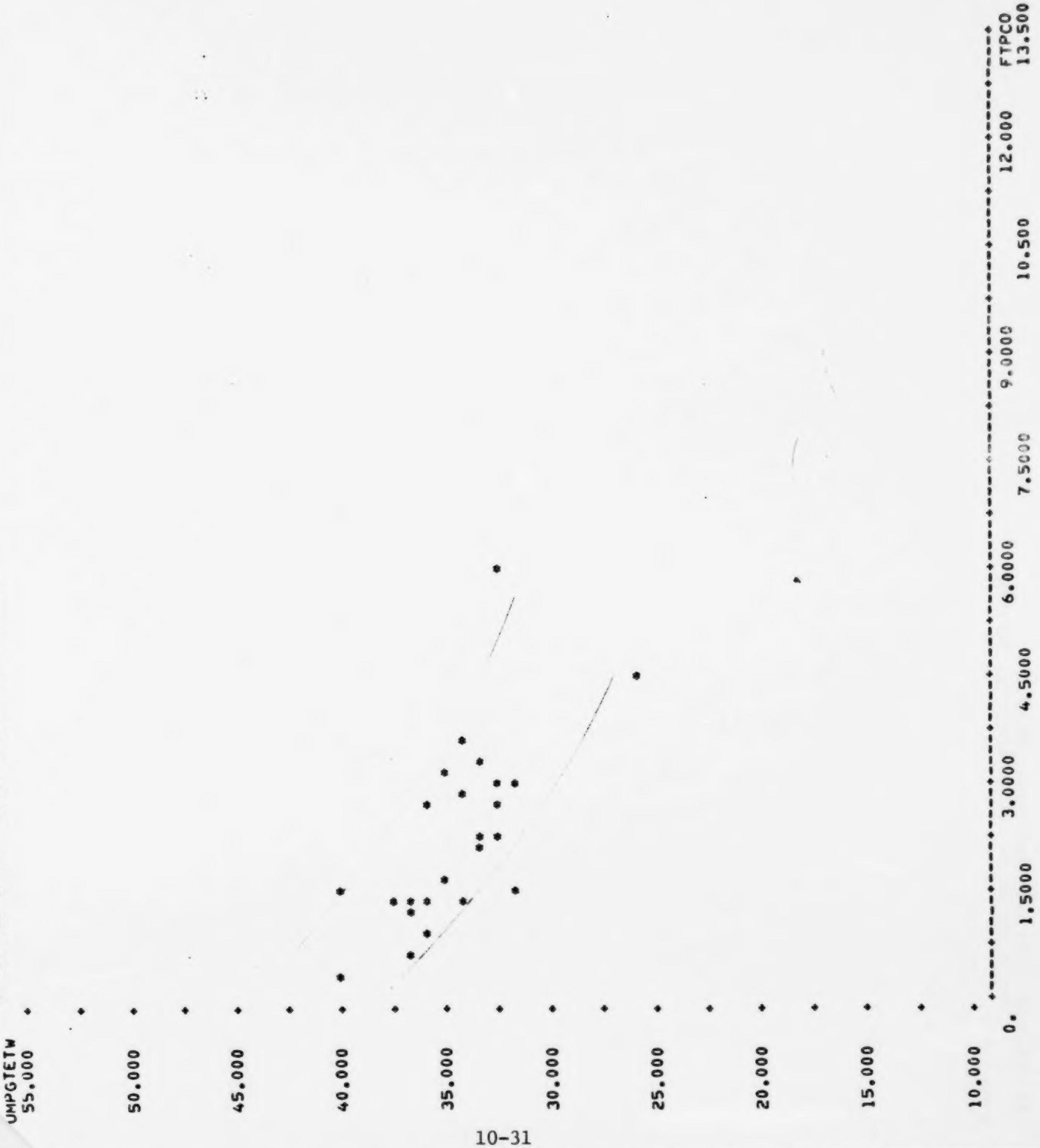

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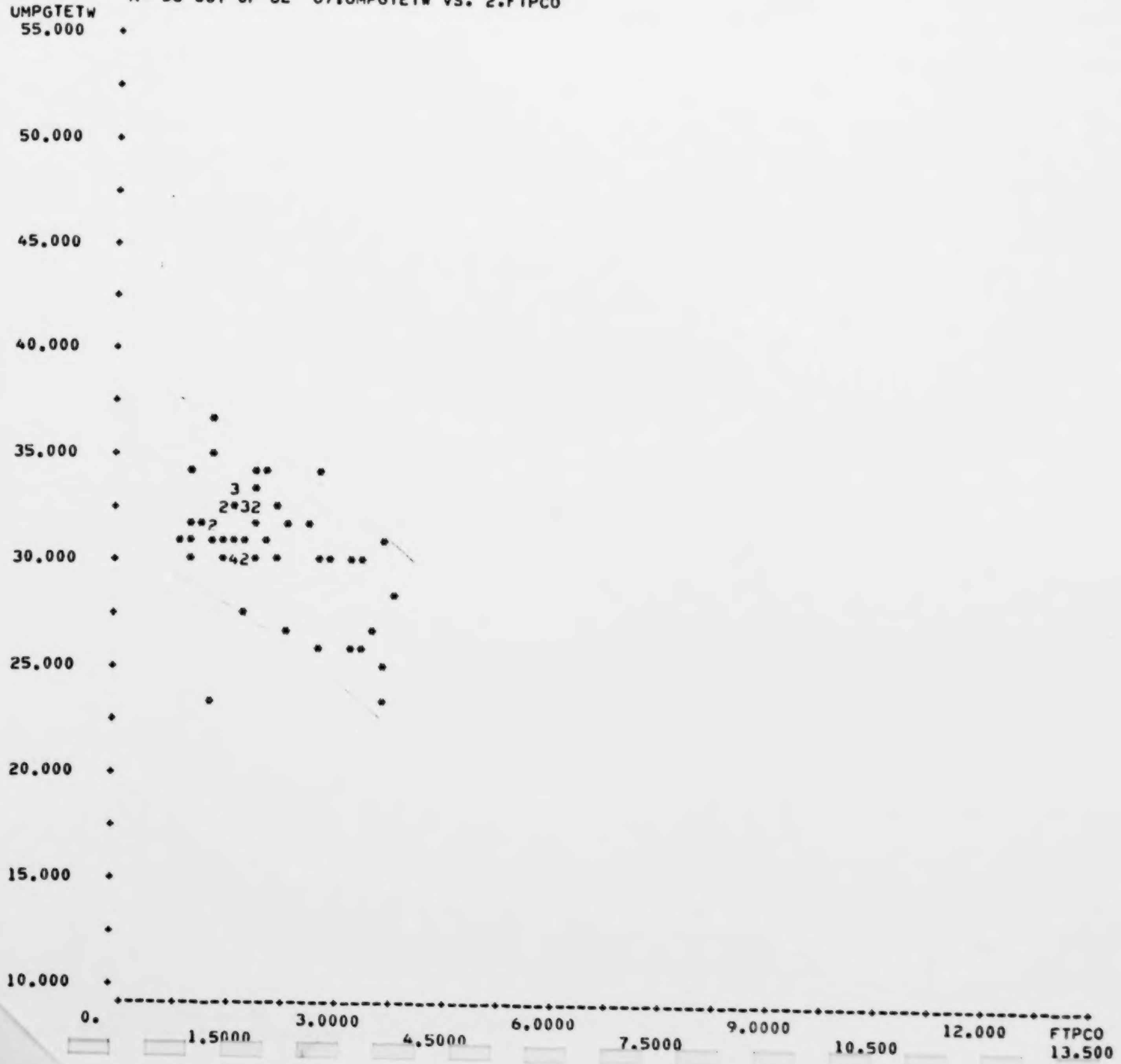

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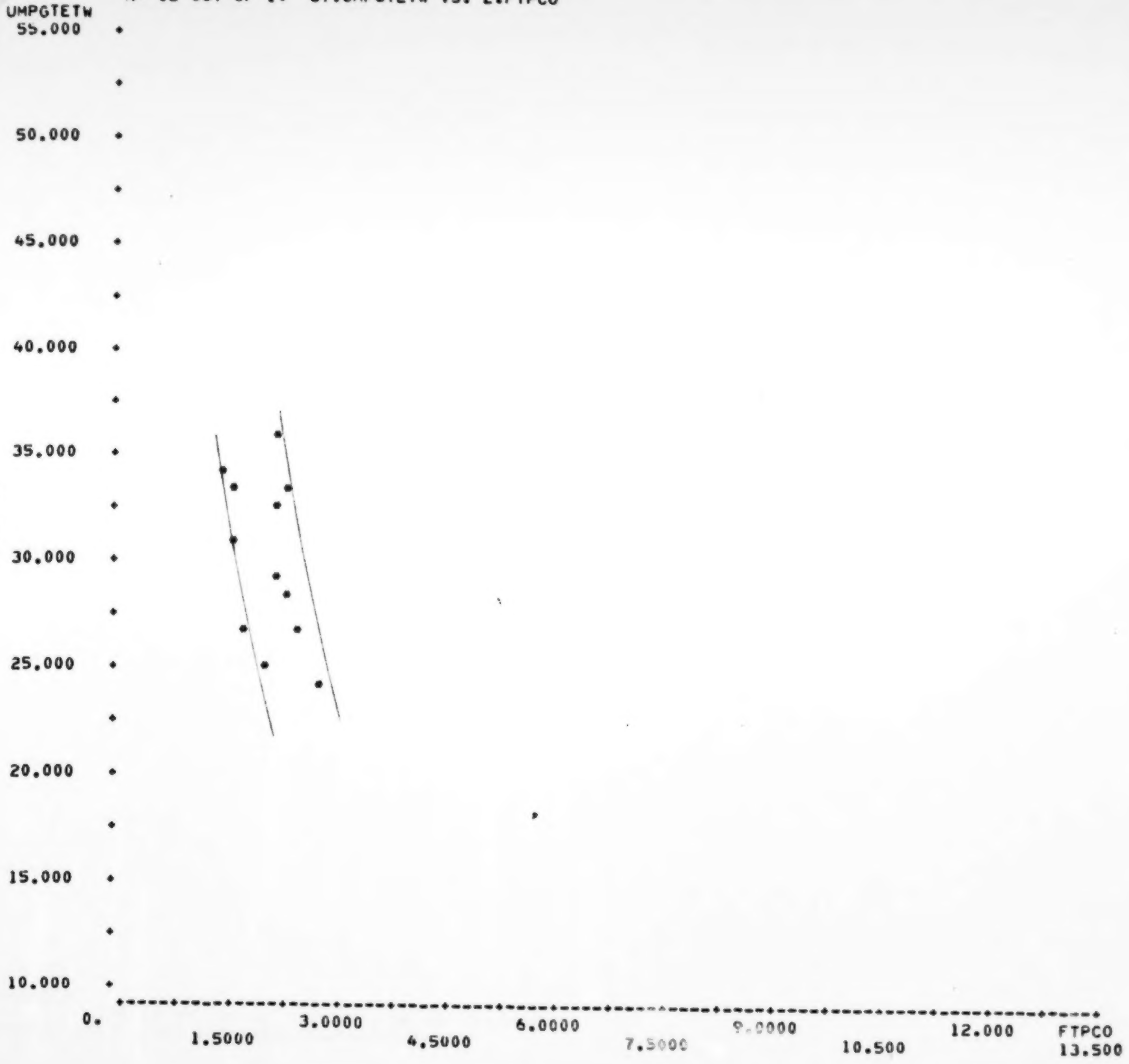

SCATTER PLOT <19> SYS1TO8:3*VTRNI(LA.LA)
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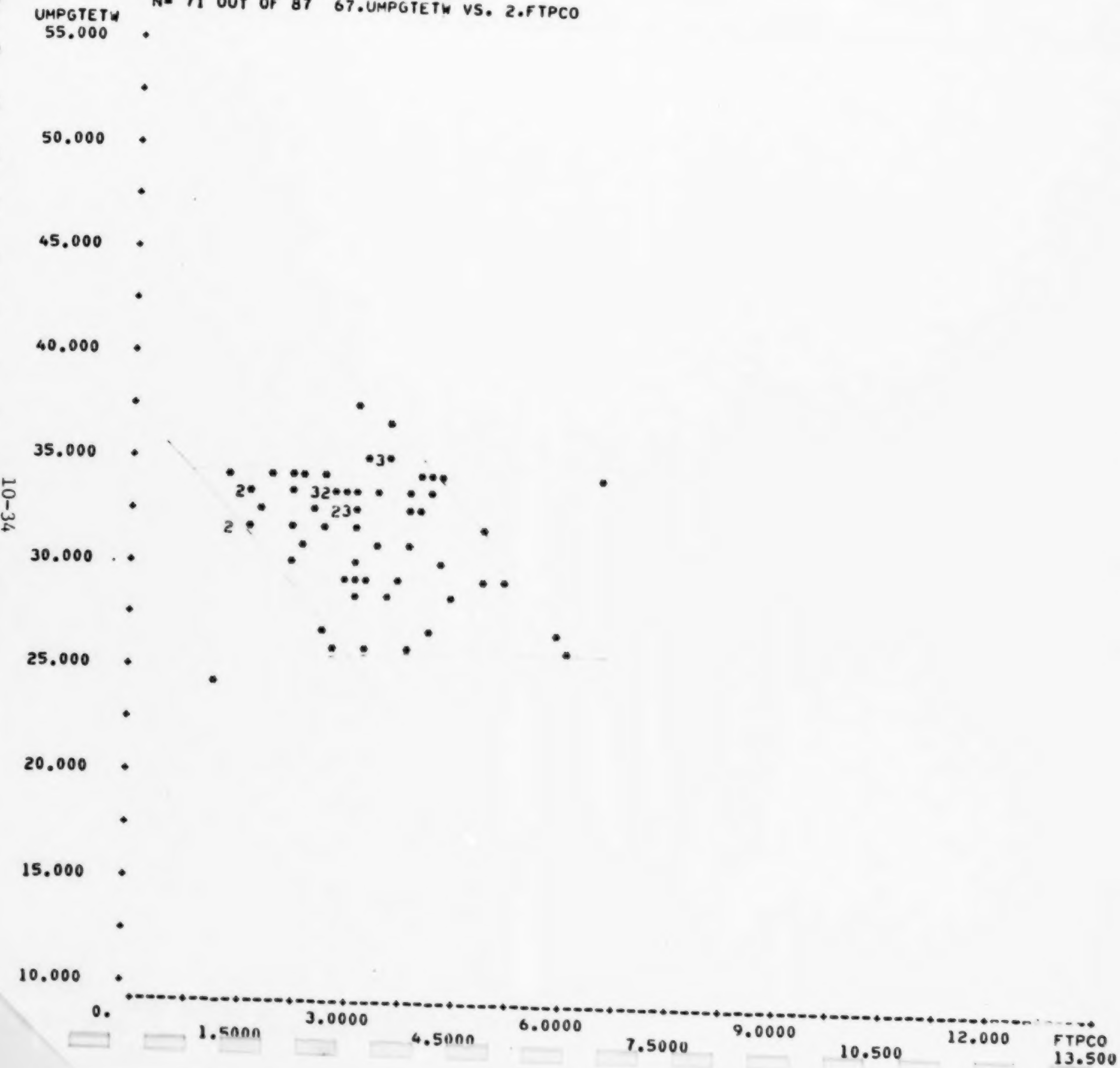

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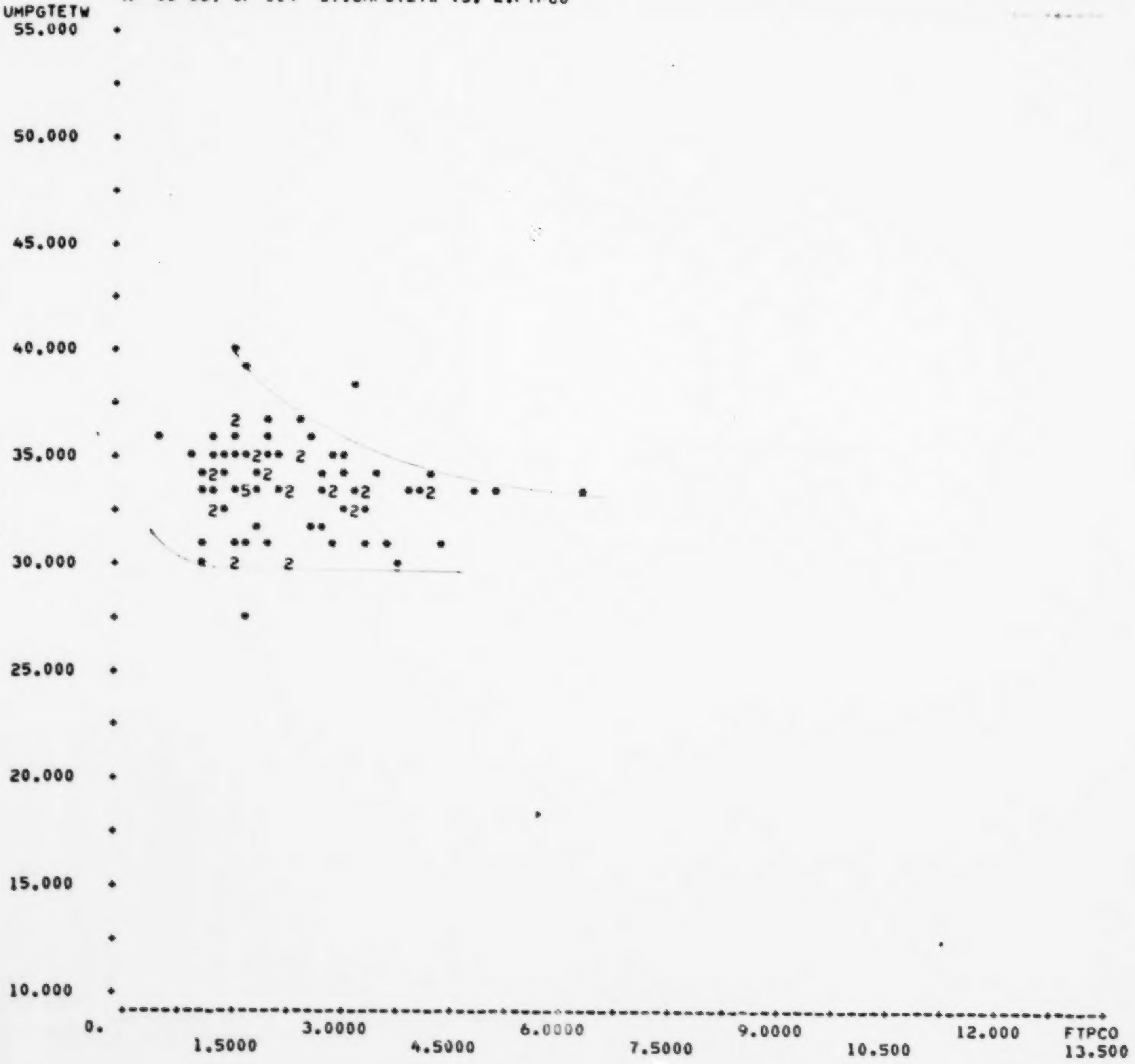
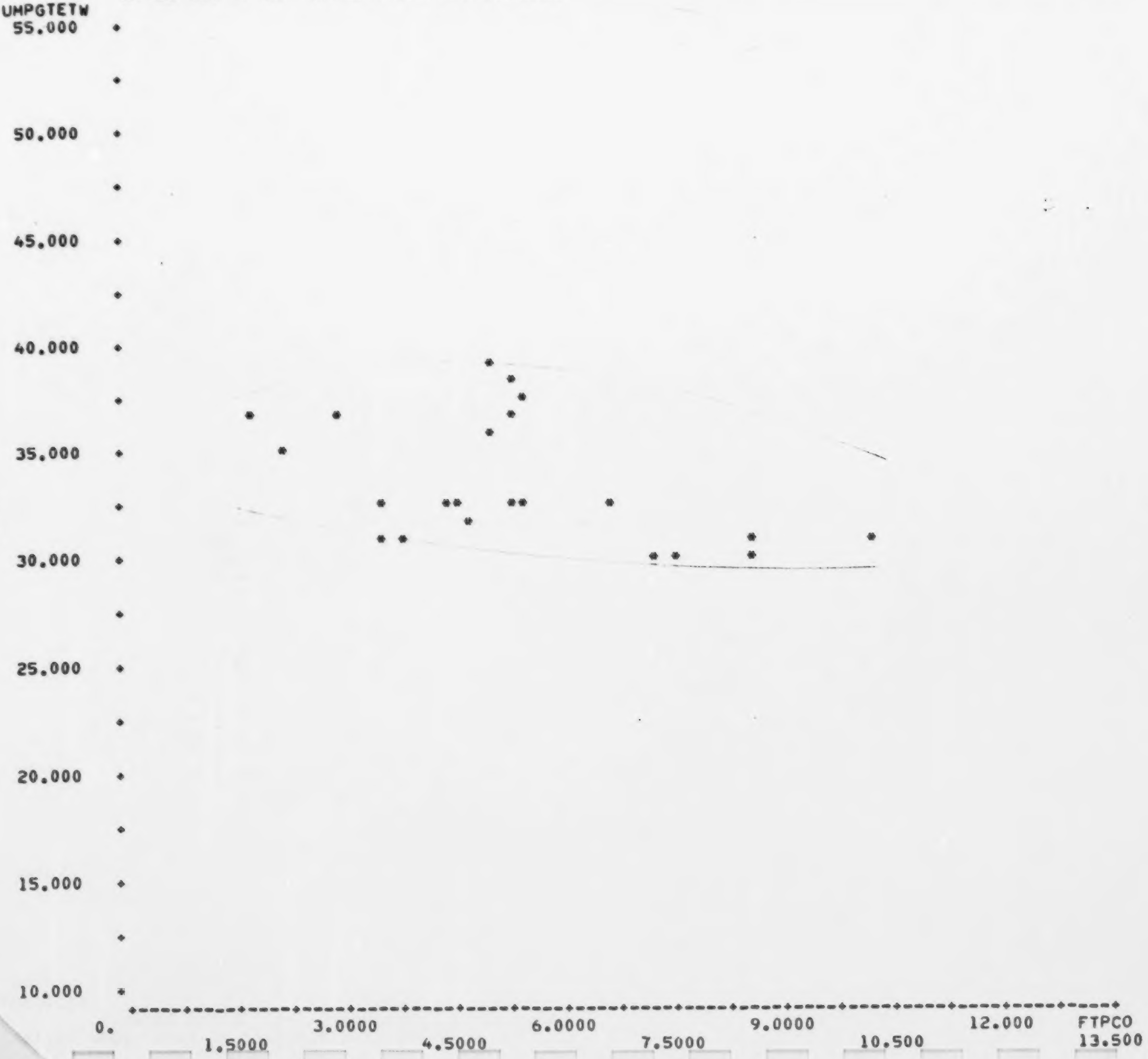


SCATTER PLOT <21> SYS1T08:5*VTRN!(LA,LA)
N= 22 OUT OF 30 67.UMPGTETW VS. 2.FTPCO



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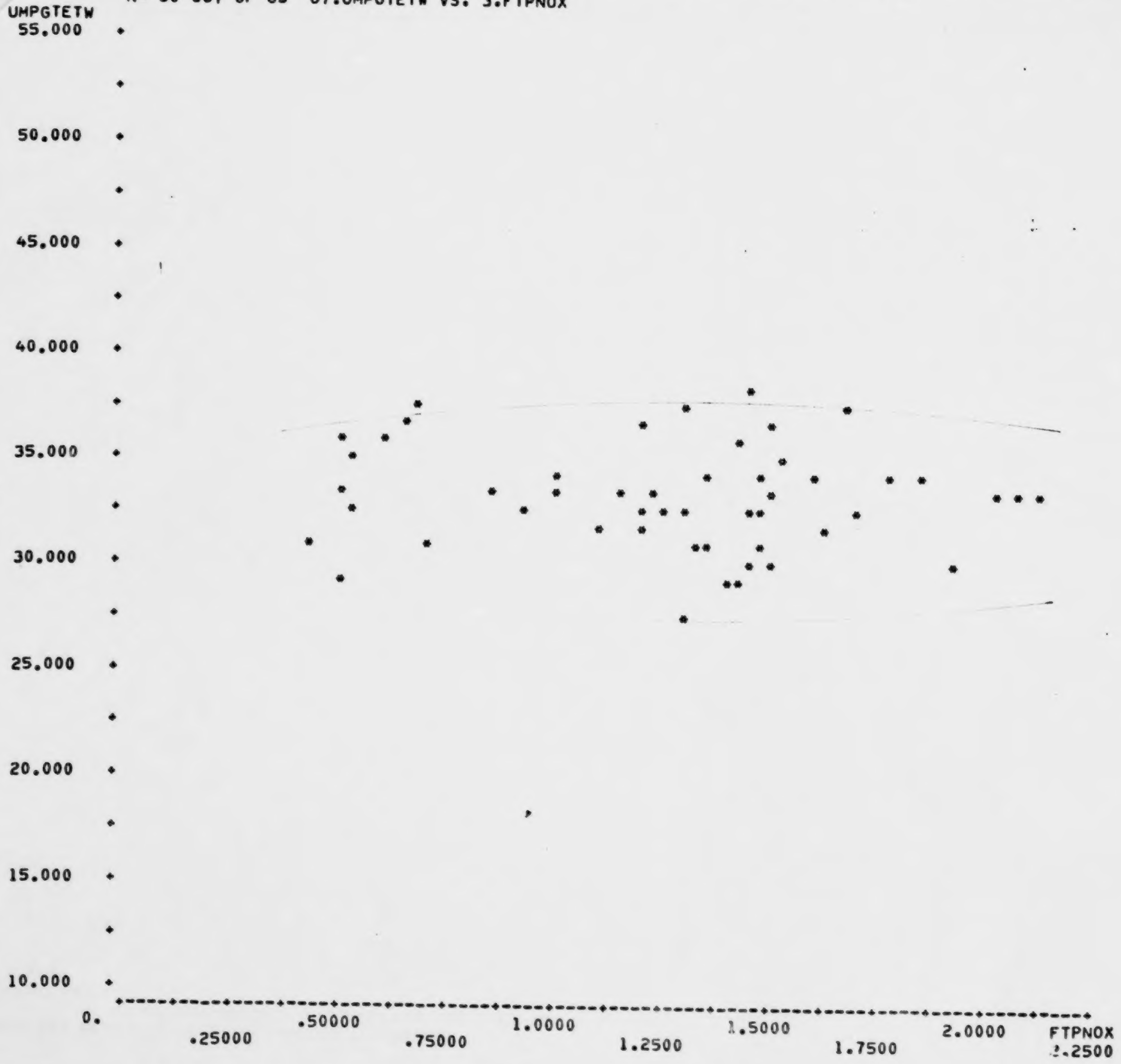
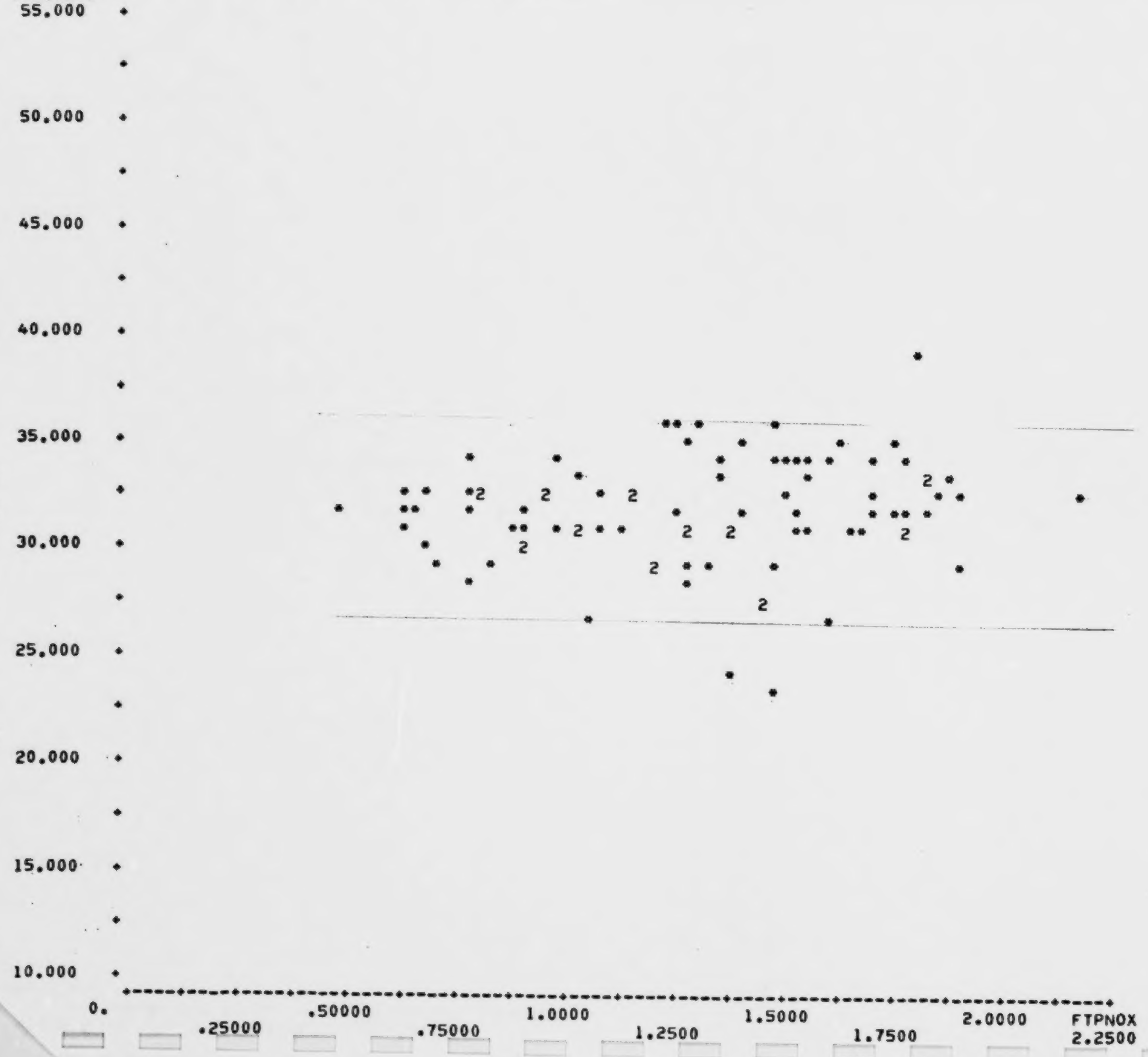
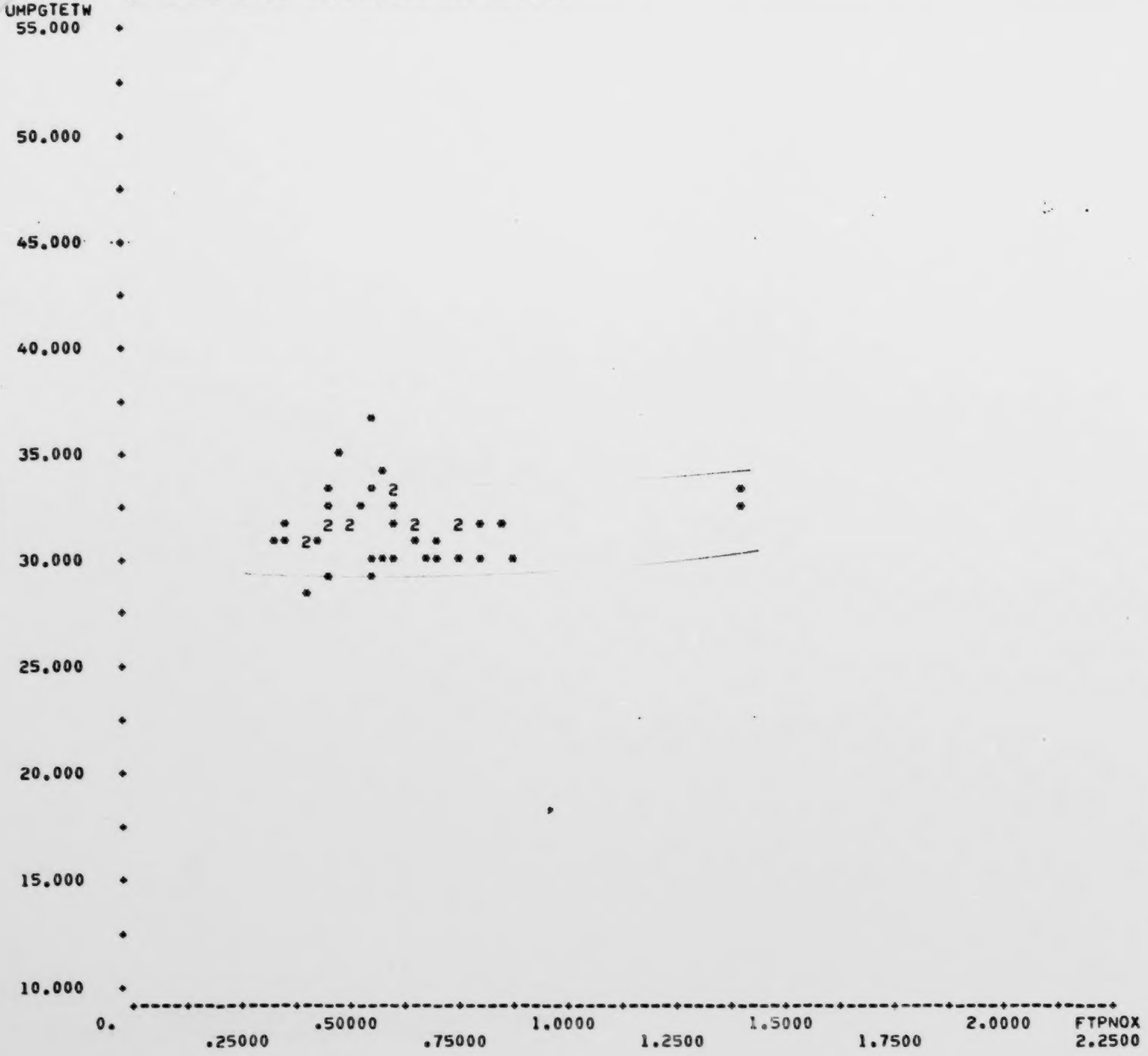
ER  BYST VAR=67:3 STRAT=V102*V28:(1,6,8),(2,3,4),(7,9) INTERVAL=(10.,55.):(0.,2.25)>
ATTER PLOT  <1> SYS1T08:1*VTRN:(CA,CA,CA)
        N= 50 OUT OF 63  67.UMPGTETW VS. 3.FTPNOX
```



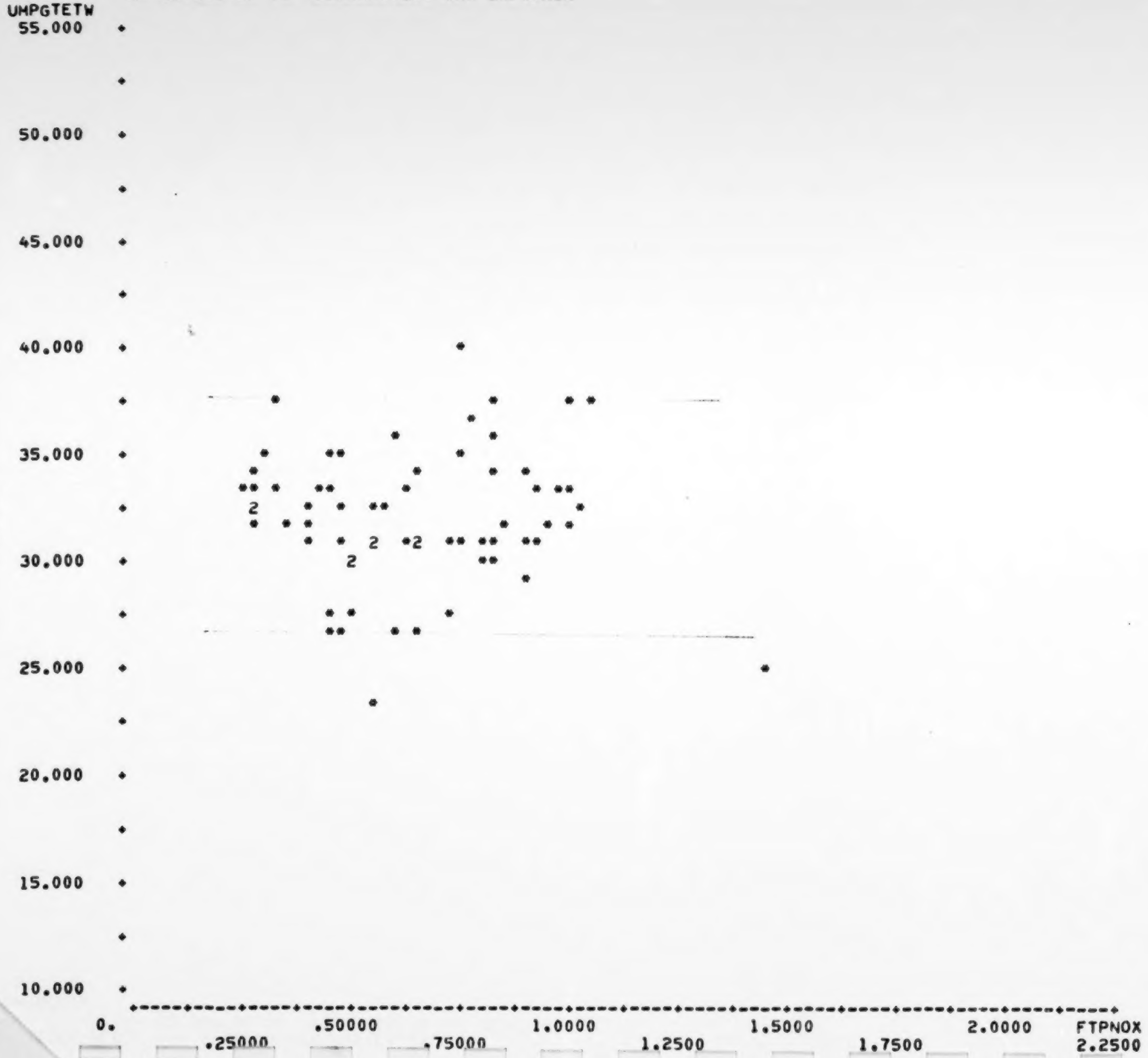
SCATTER PLOT <3> SYS1T08:3*VTRN:(CA.CA.CA)
N= 89 OUT OF 125 67.UMPGTETW VS. 3.FTPNOX



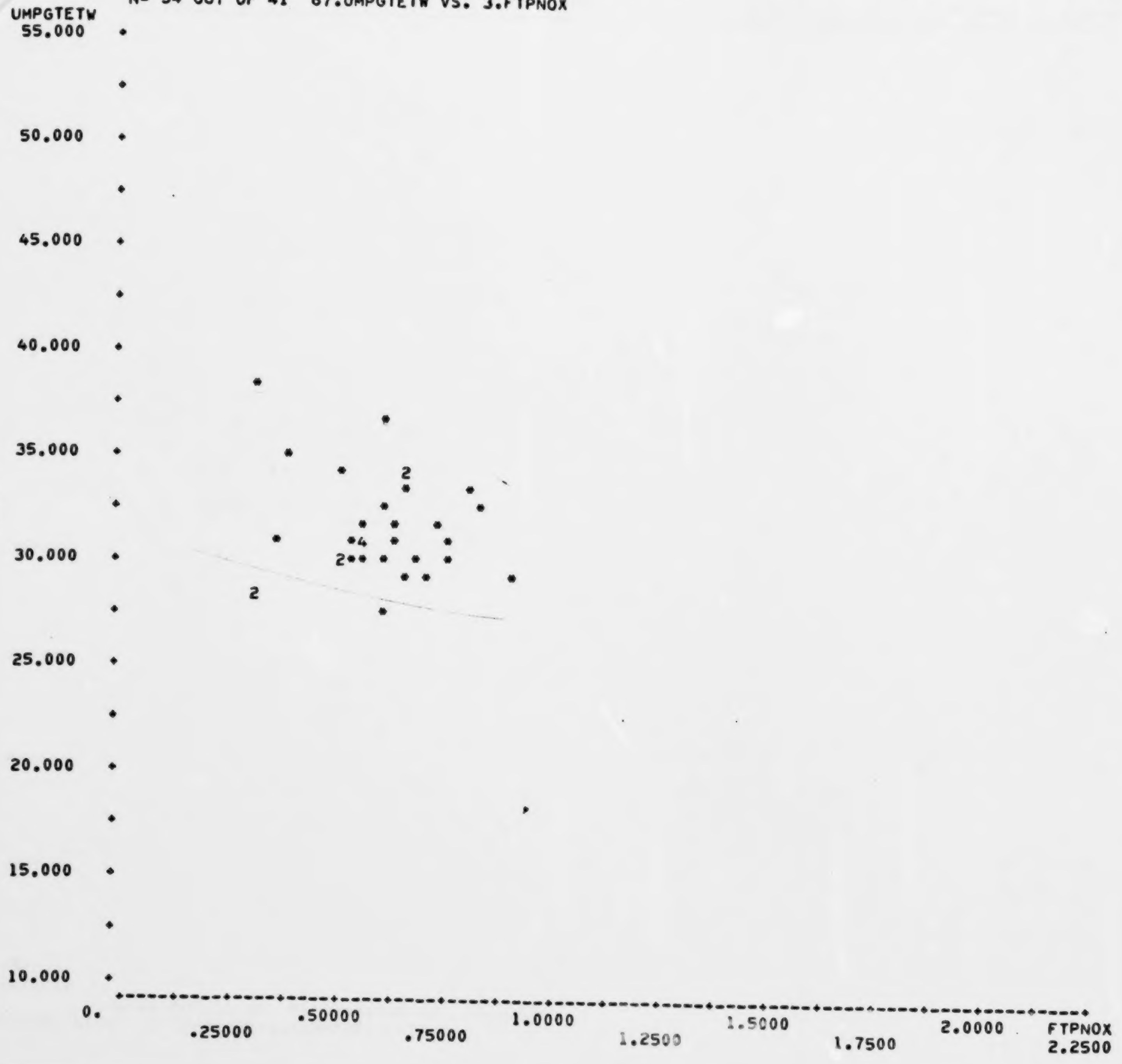
TER PLOT <4> SYS1TO8:4*VTRN:(CA,CA,CA)
N= 42 OUT OF 61 67.UMPGTETW VS. 3.FTPNOX



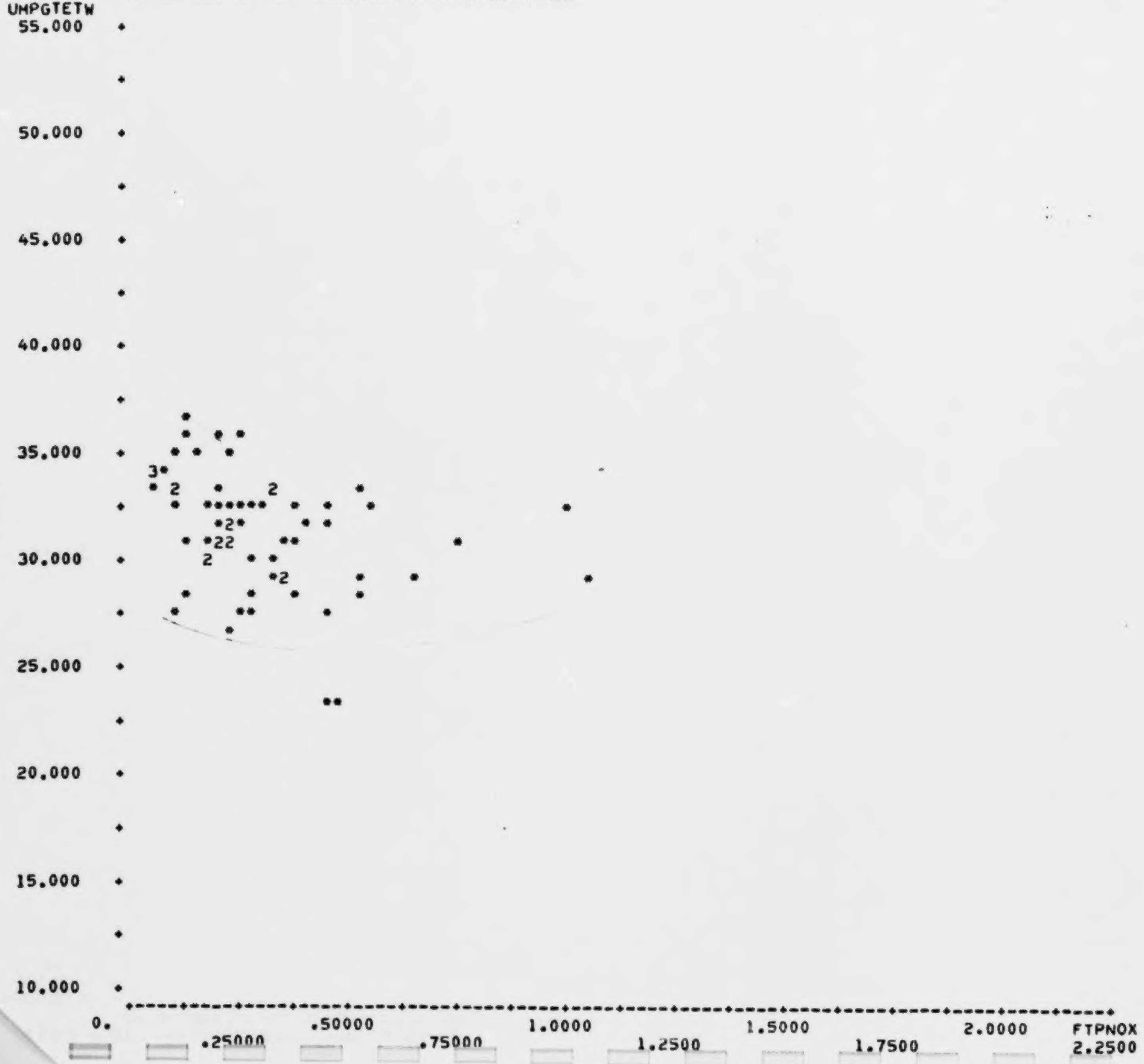
SCATTER PLOT <5> SYS1T08:5*VTRN:(CA,CA,CA)
N= 65 OUT OF 79 67.UMPGTETW VS. 3.FTPNOX



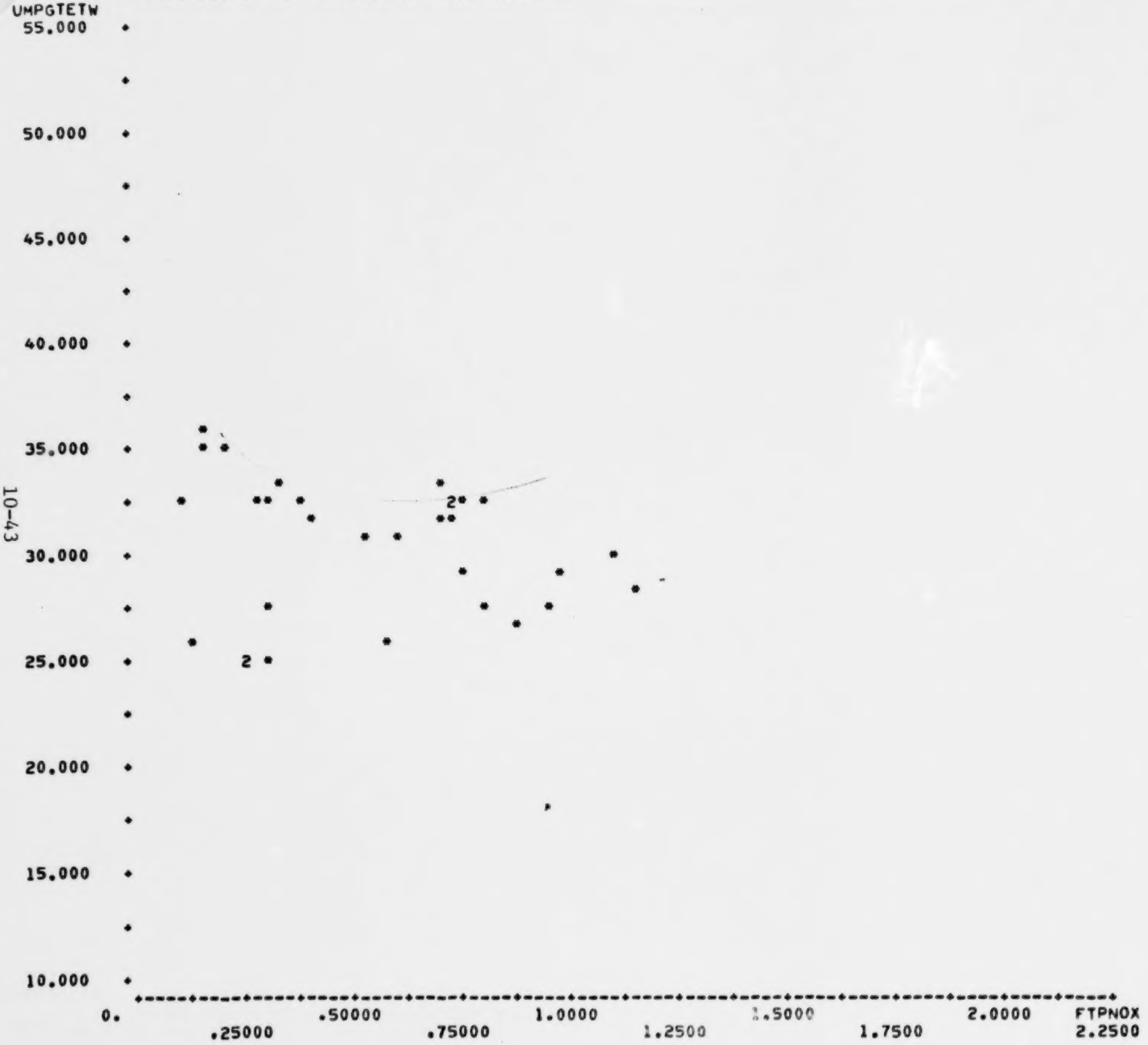
```
ATTER PLOT  <6> SYS1TO8:6*VTRN:(CA,CA,CA)
          N= 34 OUT OF 41  67.UMPGTETW VS. 3.FTPNOX
```



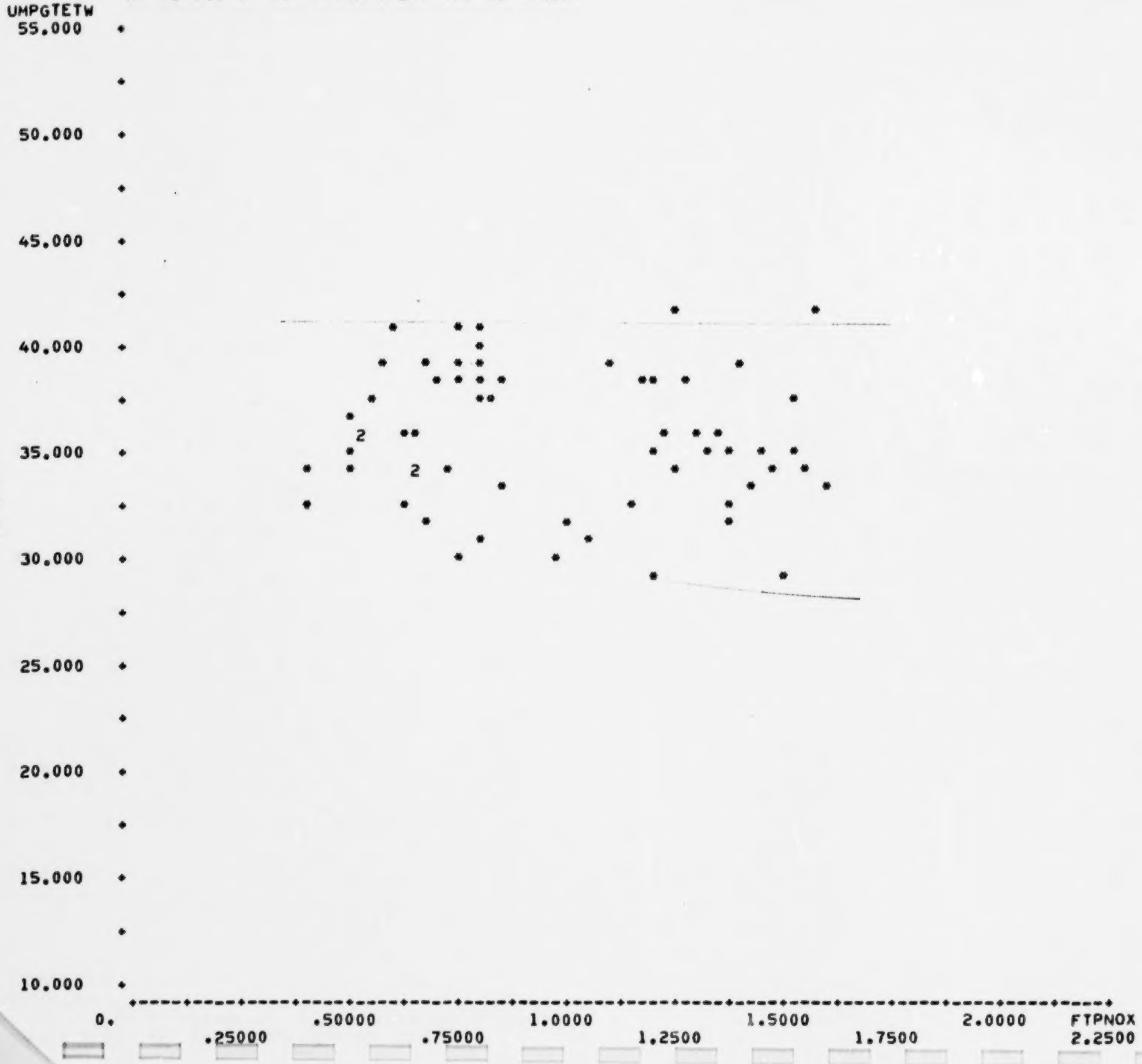
SCATTER PLOT <7> SYS1T08:7*VTRN:(CA,CA,CA)
N= 65 OUT OF 89 67.UMPGTETW VS. 3.FTPNOX



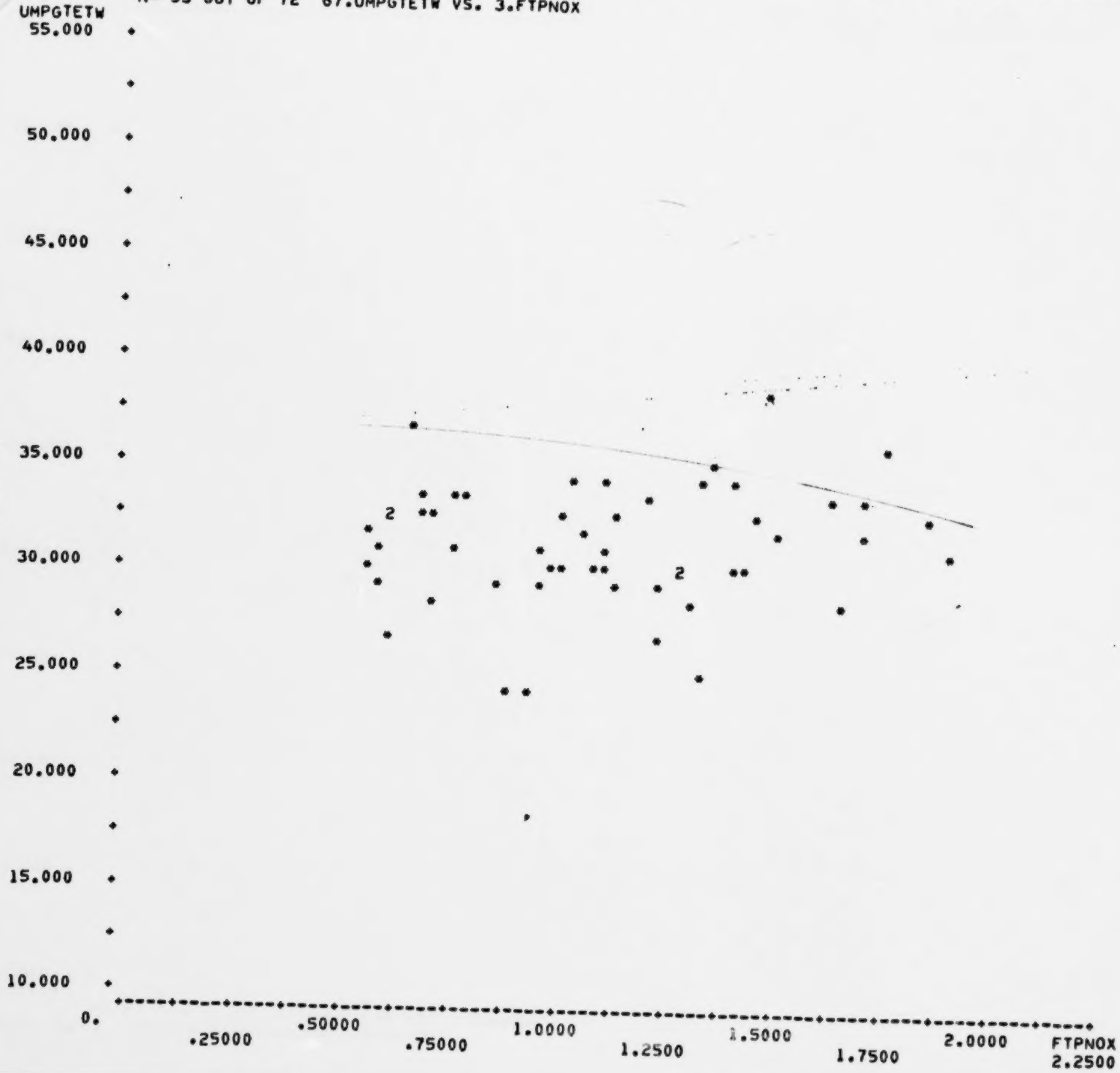
TTER PLOT <8> SYS1TO8!8*VTRN!(CA,CA,CA)
N= 31 OUT OF 42 67.UMPGTETW VS. 3.FTPNOX



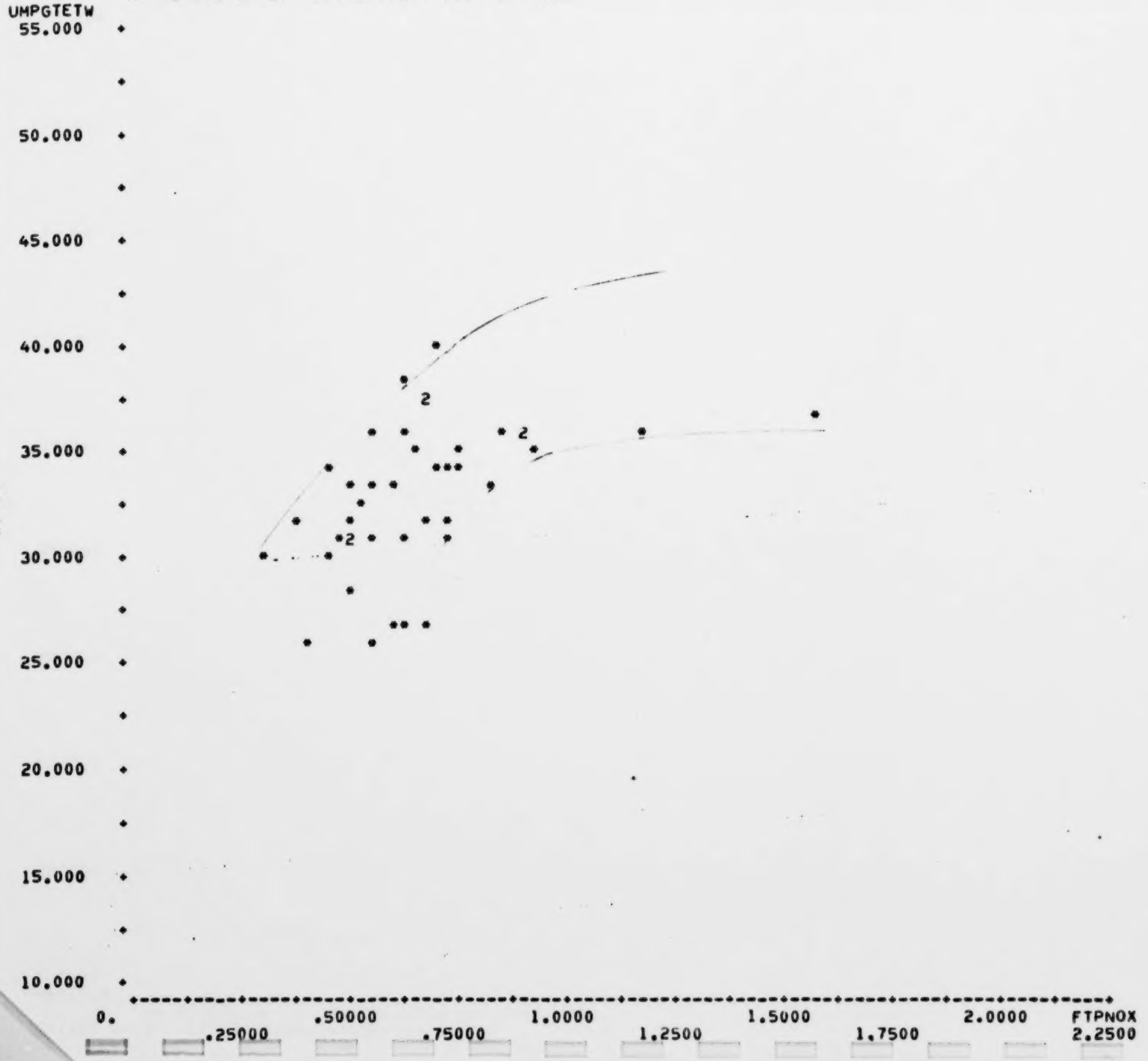
SCATTER PLOT <9> SYS1T08:1*VTRN:(CM,CM,CM)
N= 61 OUT OF 85 67.UMPGTETW VS. 3.FTPNOX



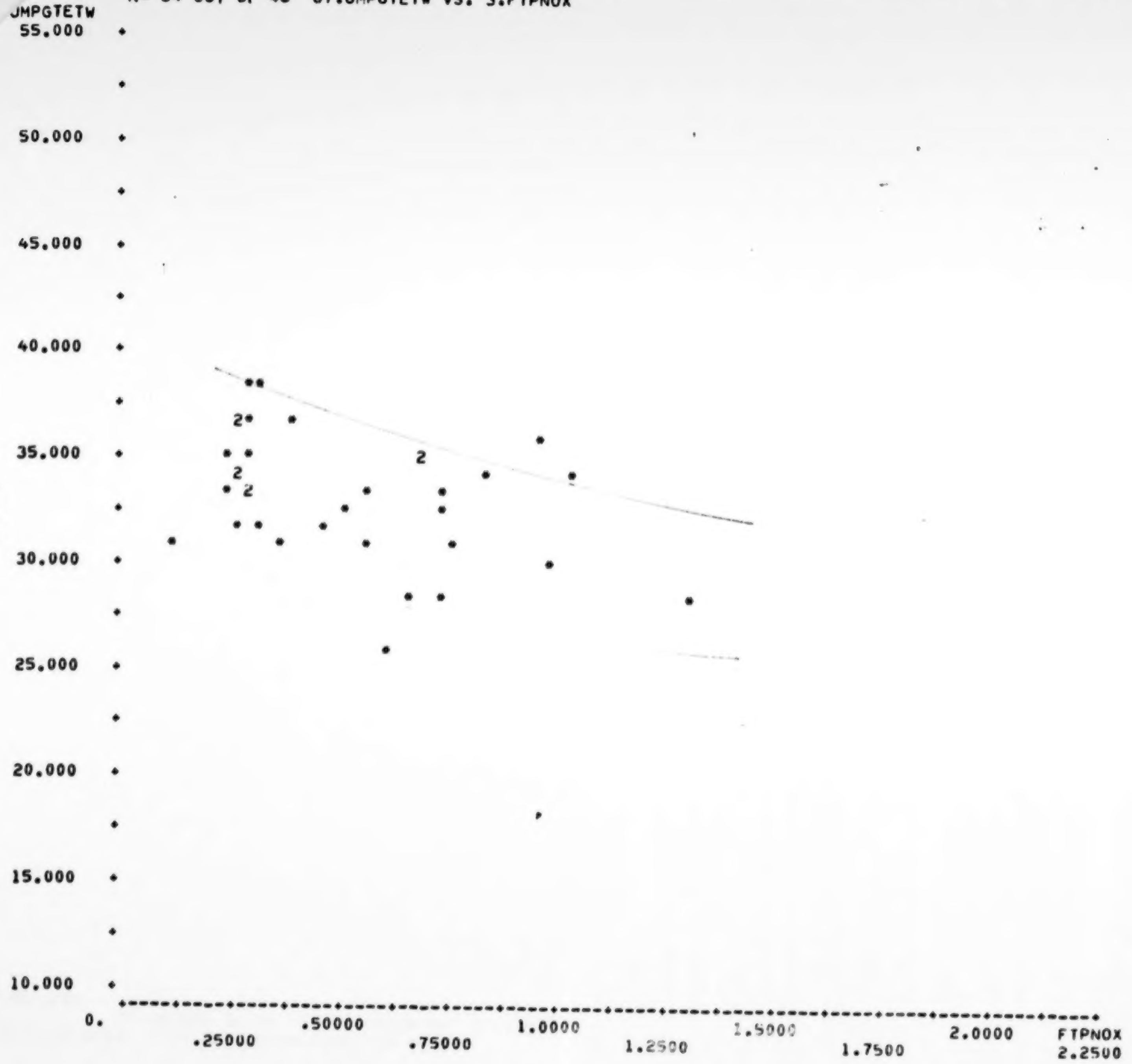
```
ATTER PLOT  <11> SYS1T08:3*VTRN:(CM,CM,CM)
        N= 53 OUT OF 72  67.UMPGTETW VS. 3.FTPNOX
```



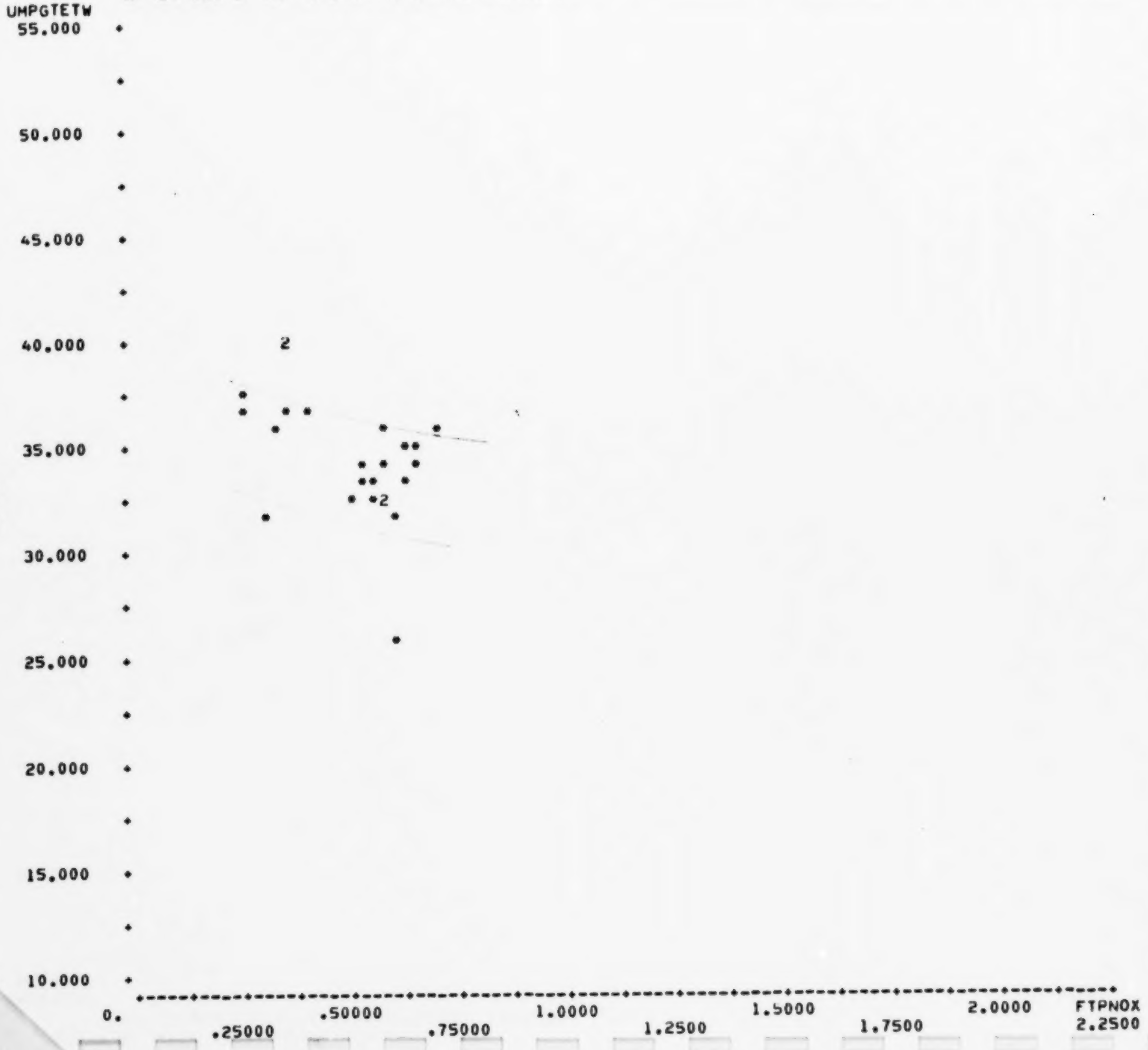
SCATTER PLOT <12> SYS1T08:4*VTRN:(CM.CM.CM)
N= 41 OUT OF 57 67.UMPGTETW VS. 3.FTPNOX



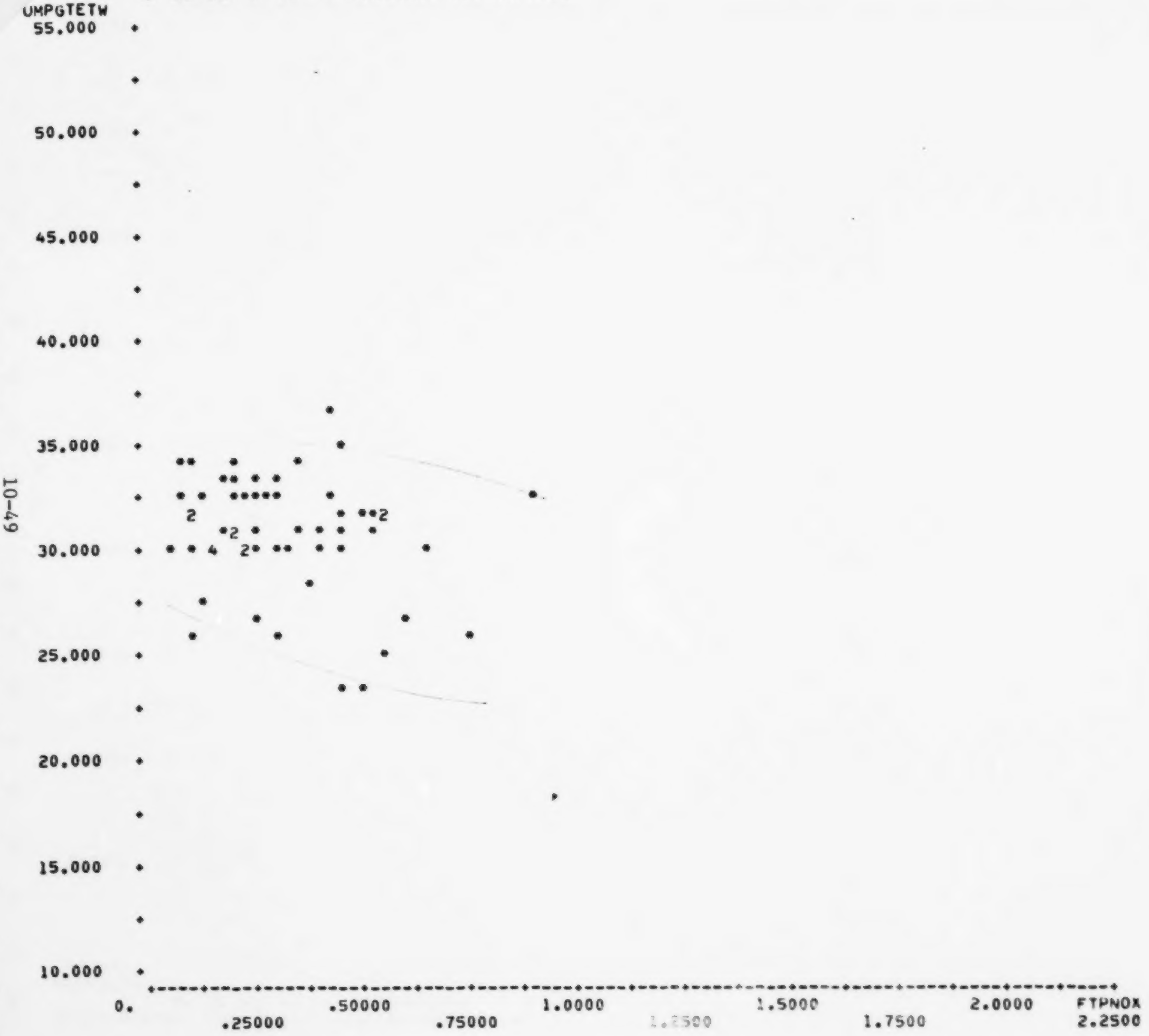
TER PLOT <13> SYS1T08:5-VTRN:(CM.CM.CM)
N= 34 OUT OF 46 67.UMPGTETW VS. 3.FTPNOX



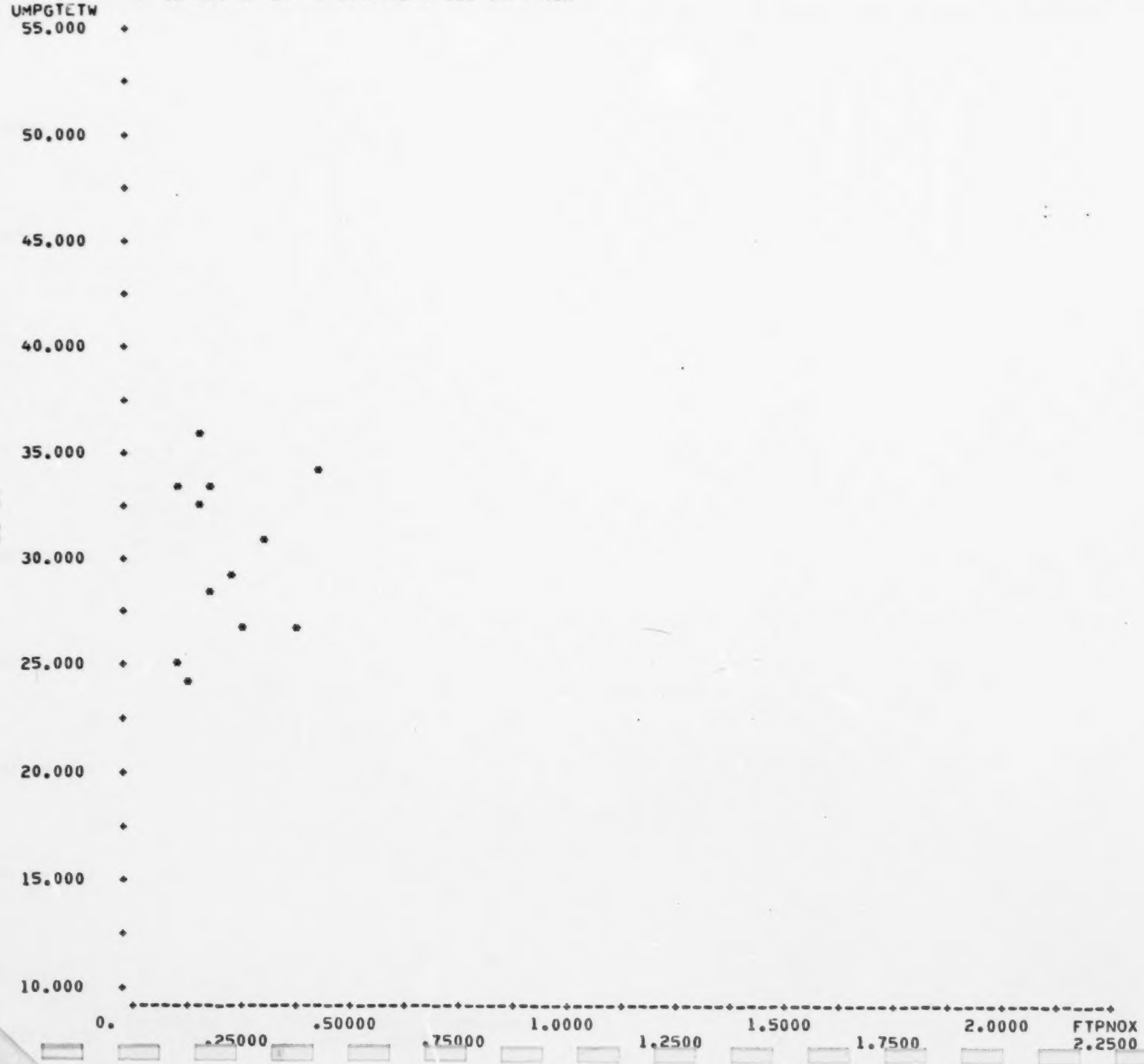
```
SCATTER PLOT  <14> SYSITO8:6*VTHNI(CM,CM,CM)
          N= 24 OUT OF 36  67.UMPGTETW VS. 3.FTPNOX
```



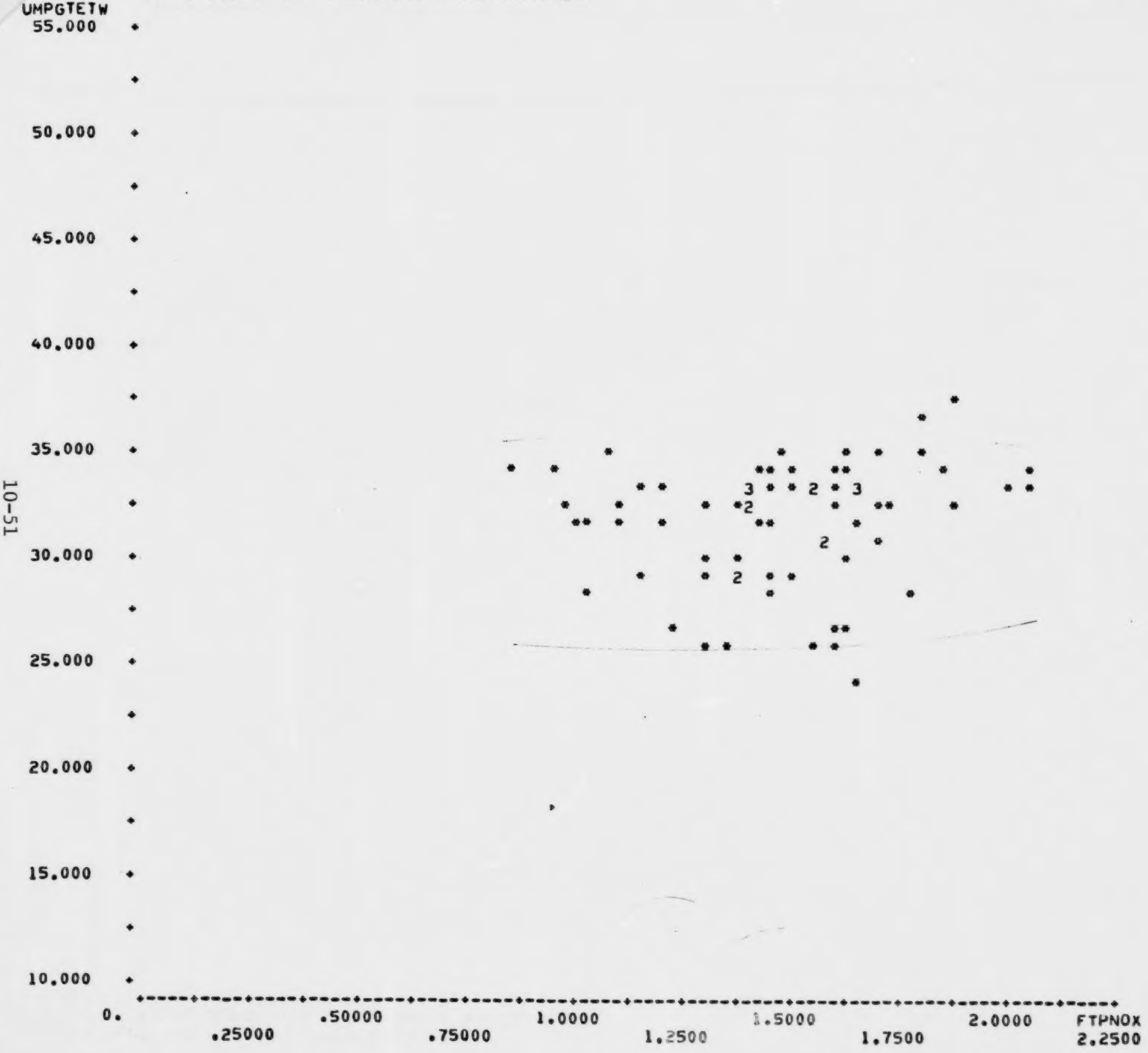
```
TER PLOT  <15> SYS1T08:7*VIRN:(CM.CM.CM)
        N= 58 OUT OF 82  67.UMPGTETW VS. 3.FTPNOX
```



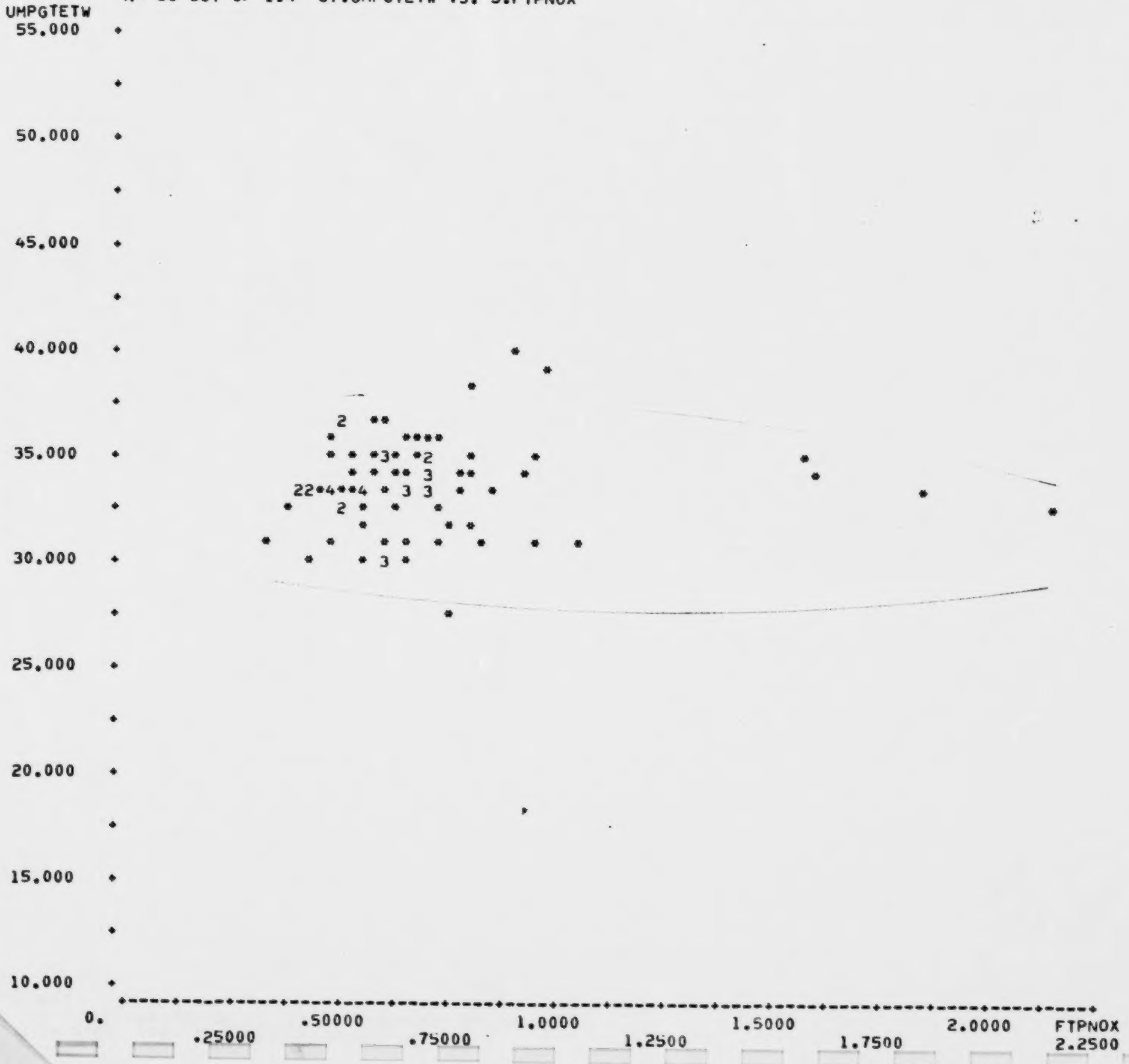
SCATTER PLOT <16> SYS1T08:8*VTRN1(CM.CM.CM)
N= 12 OUT OF 19 67.UMPGTETW VS. 3.FTPNOX



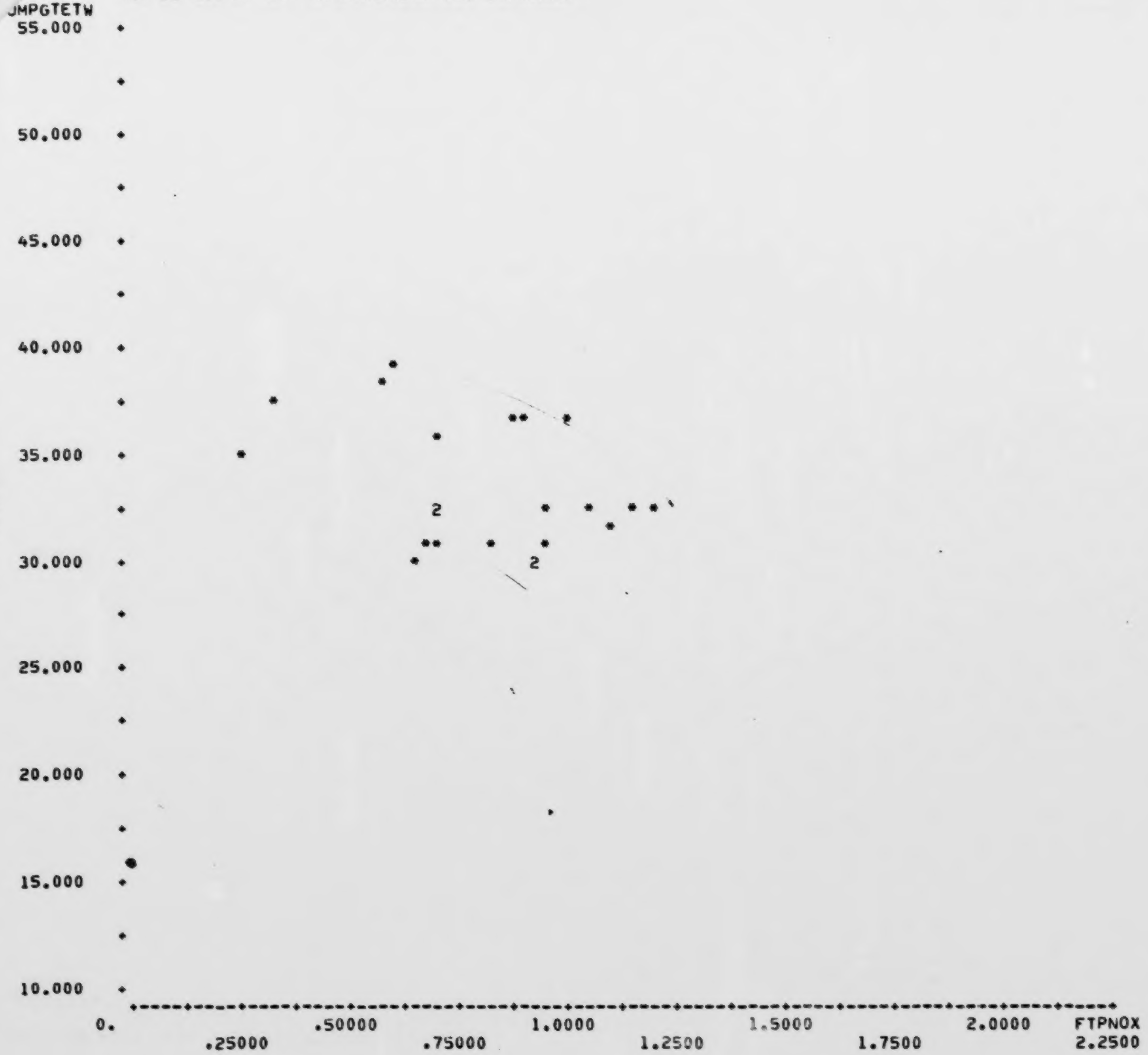
```
TTER PLOT  <19> SYS1T08:3*VTRN:(LA,LA)
        N= 71 OUT OF 87  67.UMPGTETW VS. 3.FTPNOX
```



SCATTER PLOT <20> SYS1T08:4*VTRN:(LA,LA)
N= 86 OUT OF 114 67.UMPGTETW VS. 3.FTPNOX



```
.TER PLOT  <21> SYSITU8:5*VIRN:(LA,LA)
        N= 22 OUT OF 30  67.UMPGTETW VS. 3.FTPNOX
```



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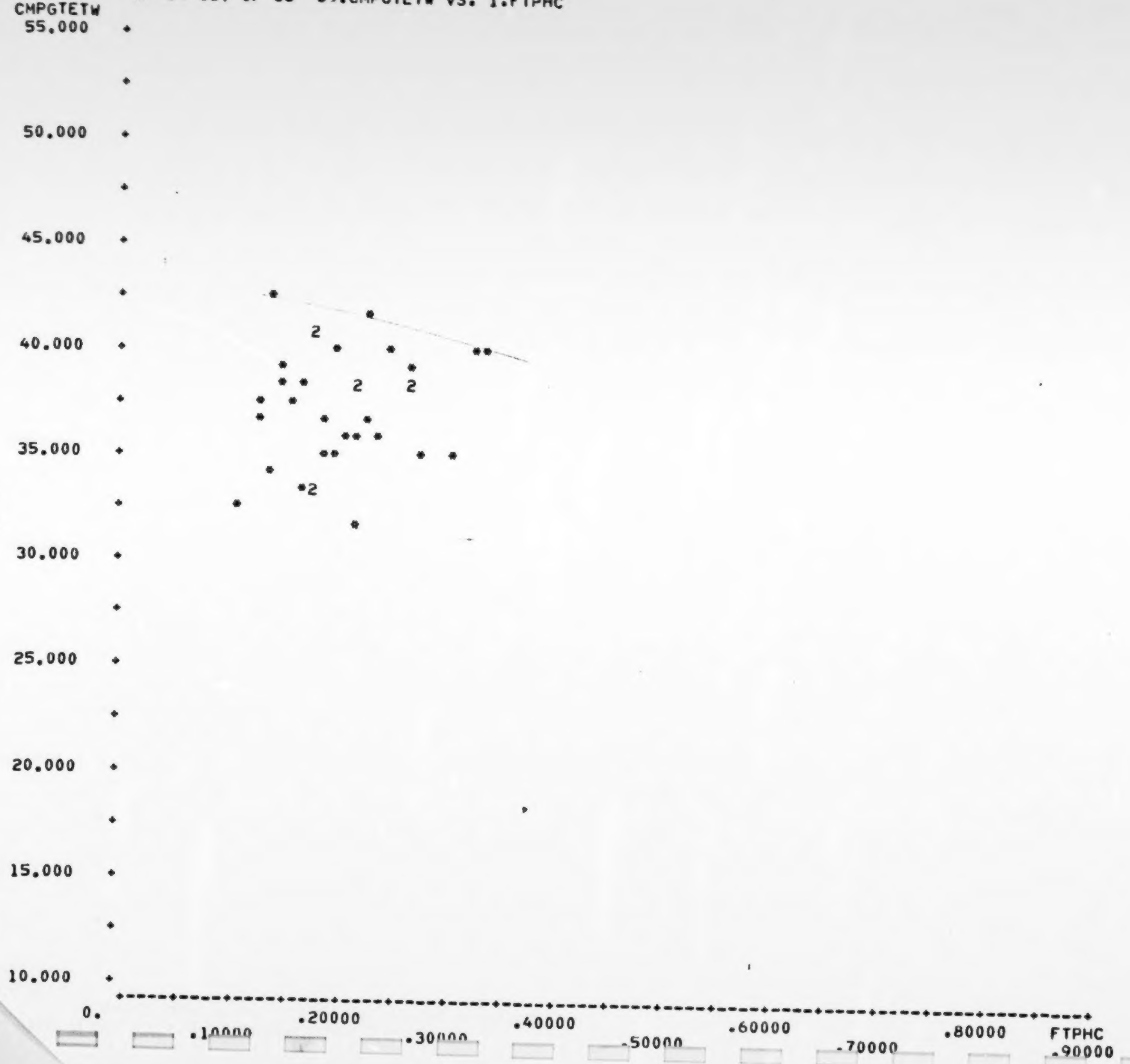
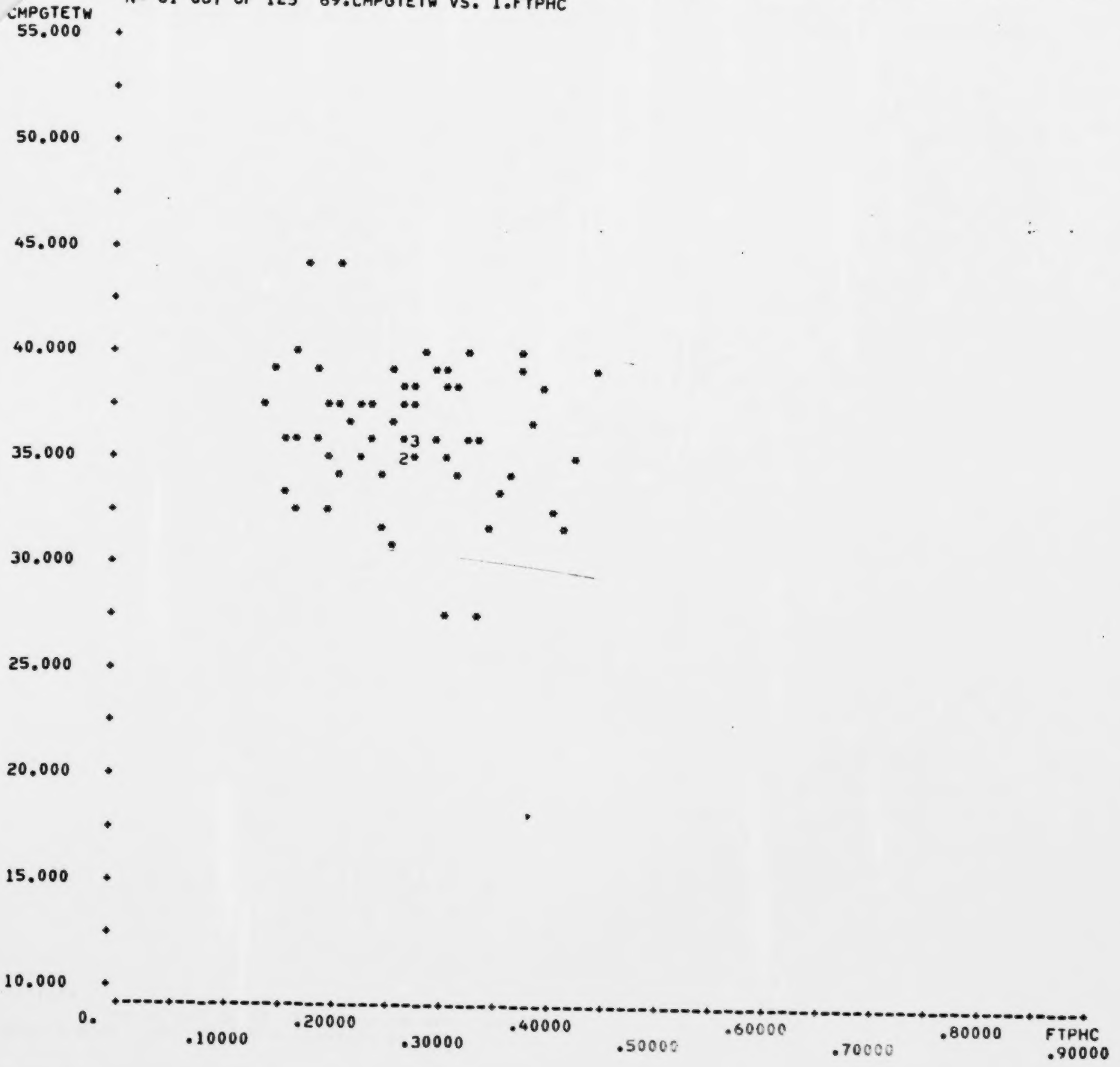
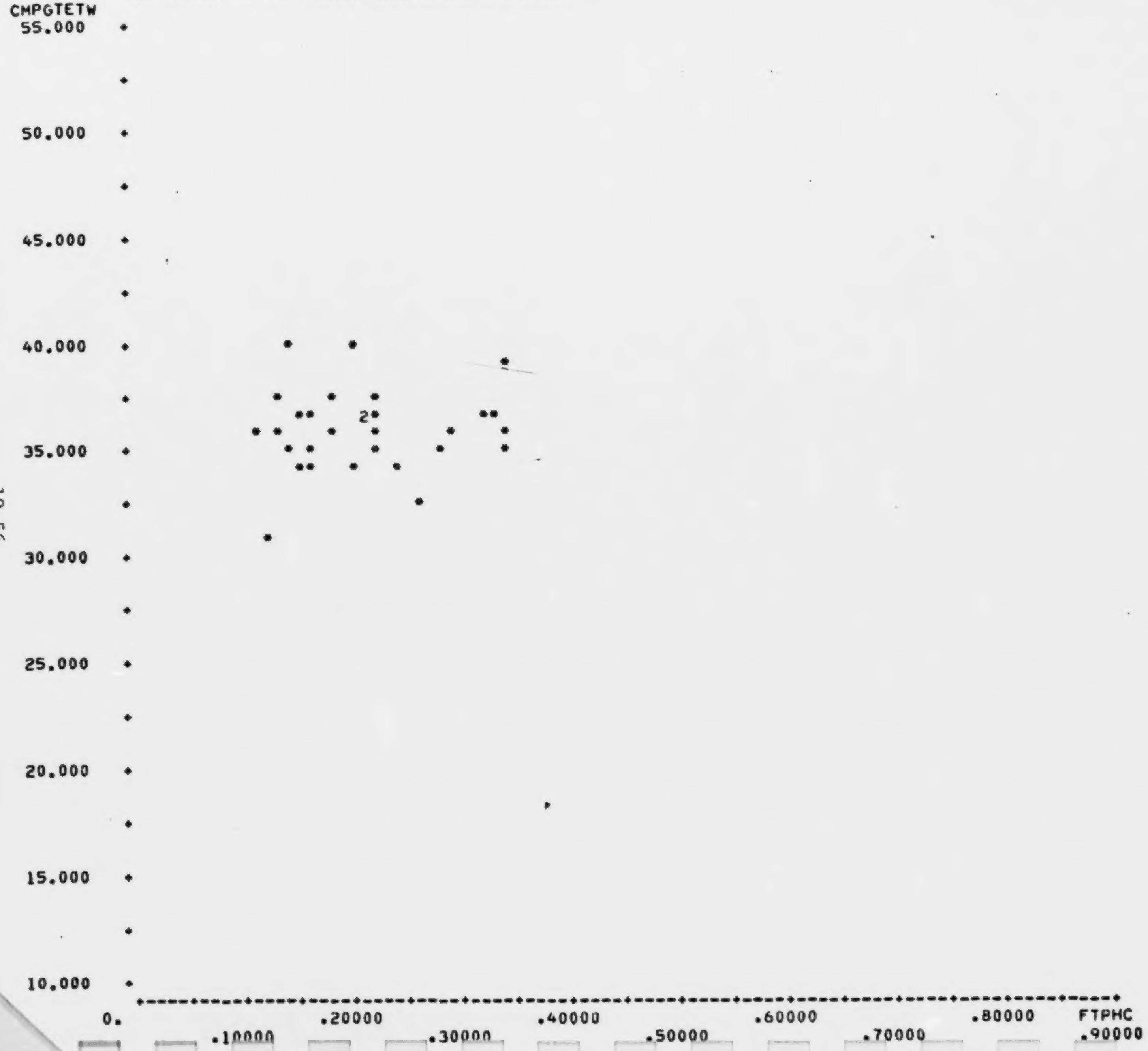
<SCATTER  BYST VAR=69!1 STRAT=V102*V28!(1,6,8),(2,3,4),(7,9) INTERVAL=(10.,55.)!(0.,0.9)>
SCATTER PLOT  <1> SYS1T08!1*VTRN!(CA,CA,CA)
           N= 34 OUT OF 63  69.CMPGTETW VS. 1.FTPHC
```



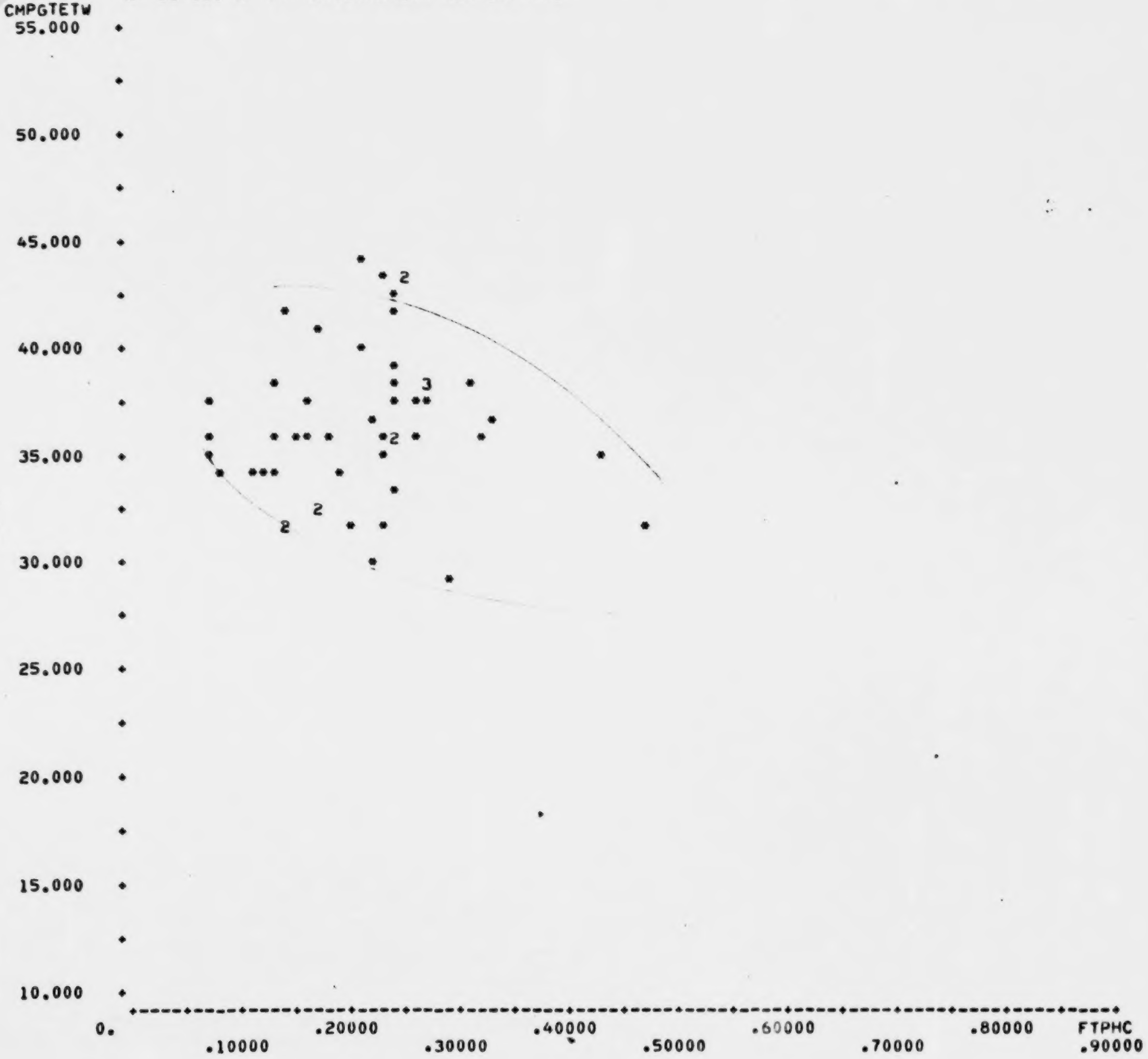
```
TER PLOT  <J> SYS1TOB:3*VIRN:(CA,CA,CA)
          N= 61 OUT OF 125  69.CMPGTETW VS. 1.FTPHC
```



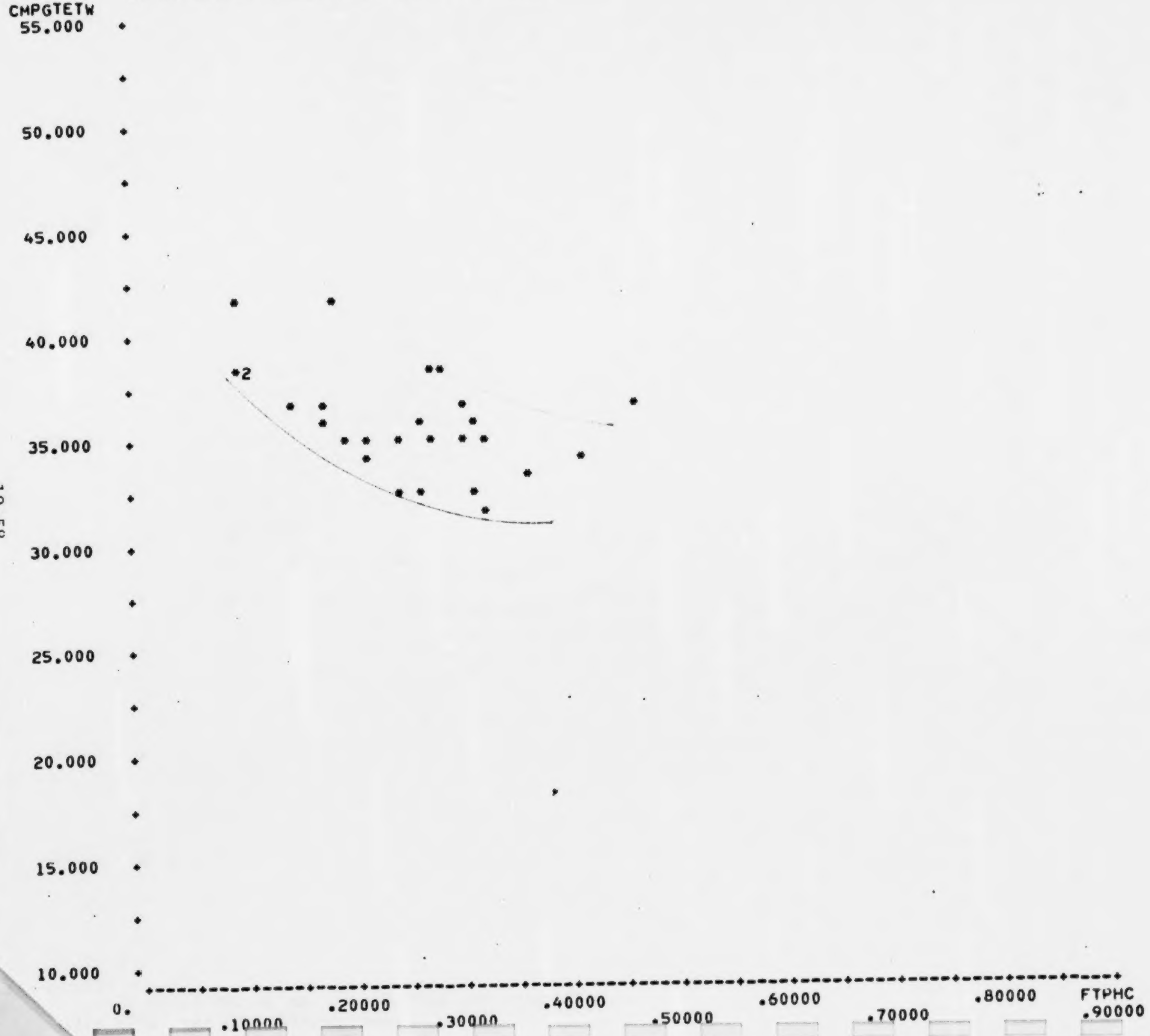
SCATTER PLOT <4> SYS1T08:4*VTHN:(CA.CA.CA)
N= 30 OUT OF 61 69.CMPGTETW VS. 1.FTPHC



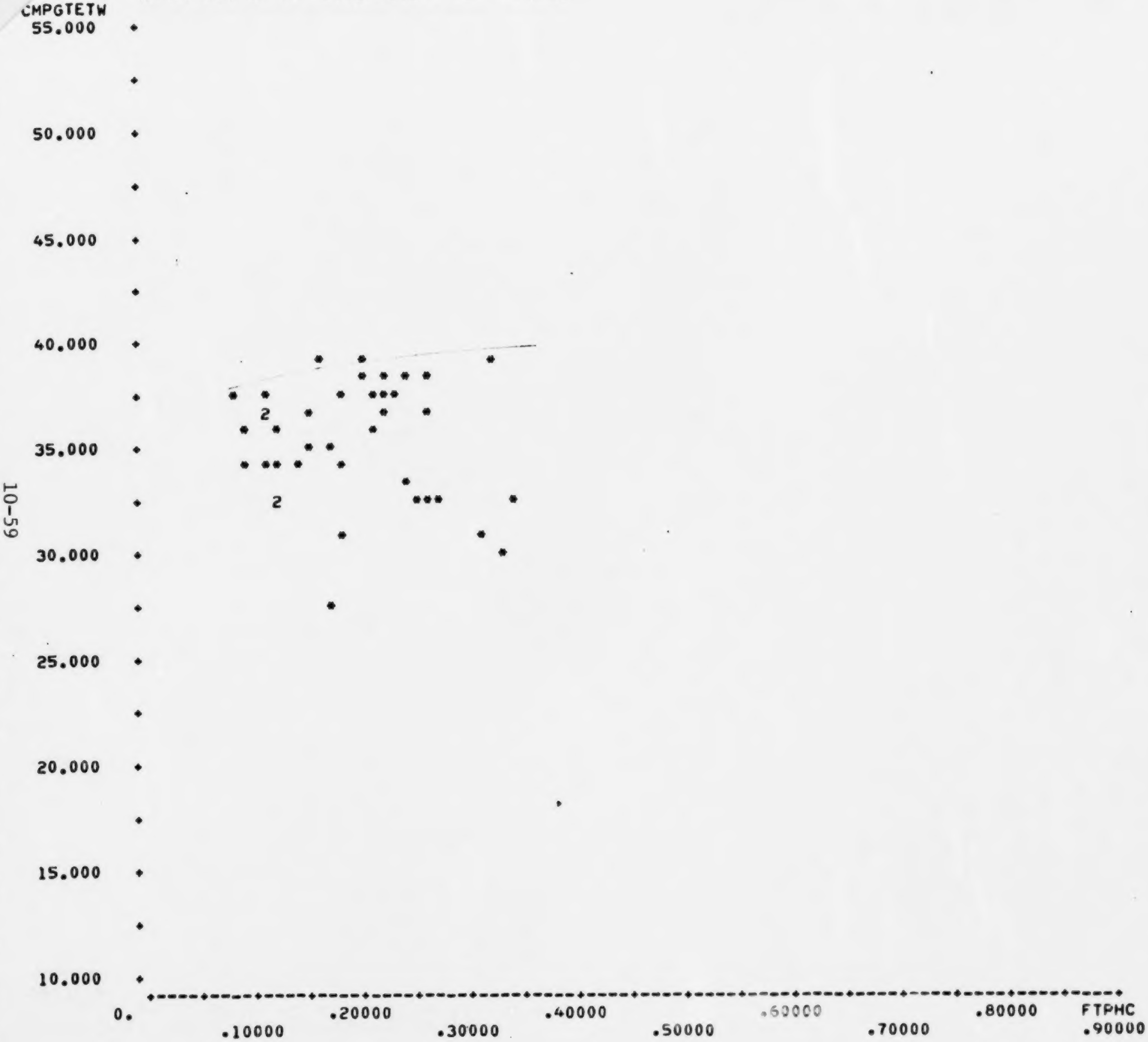
ATTER PLOT <5> SYS1T08:5*VTRN:(CA,CA,CA)
N= 51 OUT OF 79 69.CMPGTETW VS. 1.FTPHC



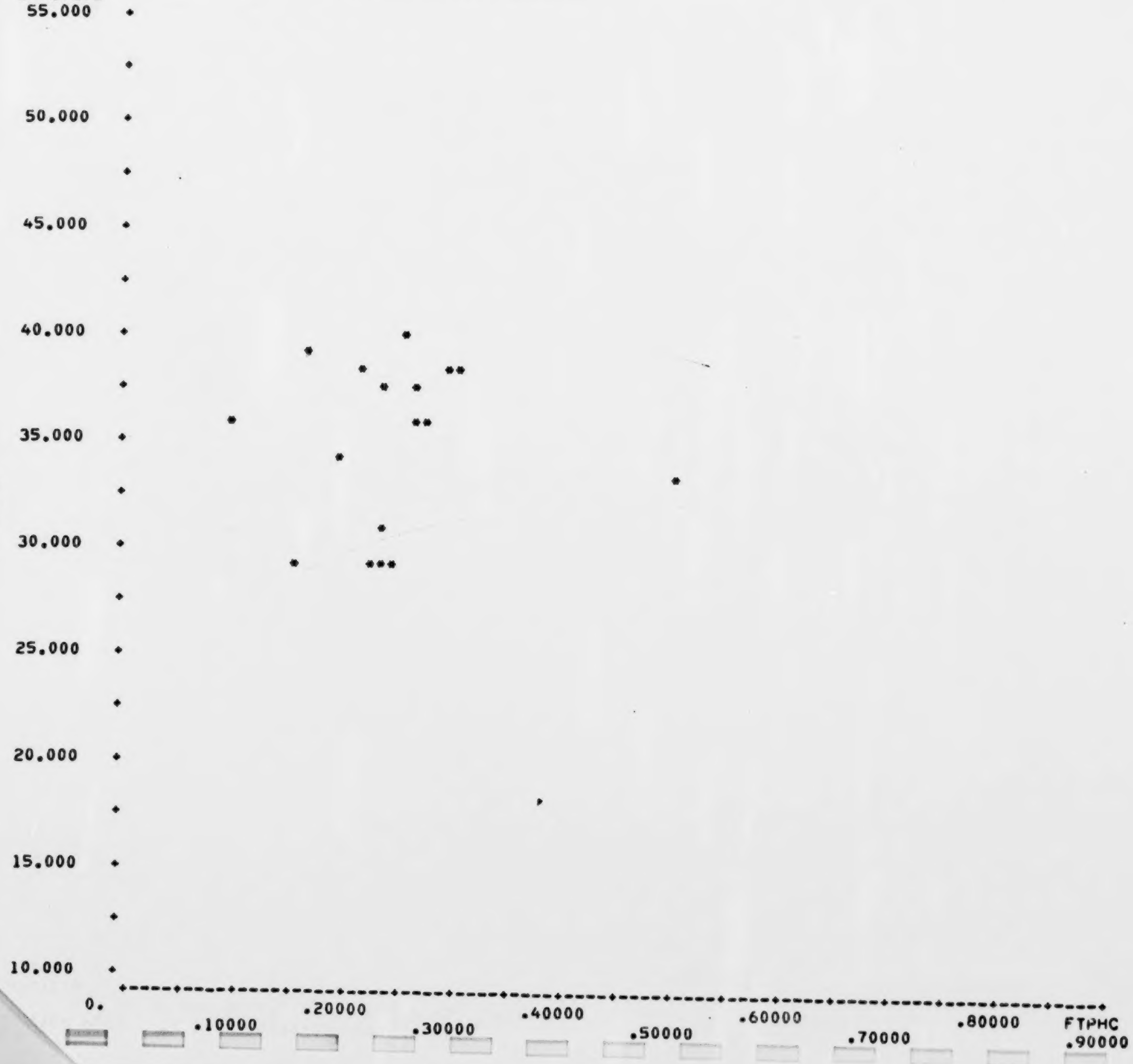
SCATTER PLOT <6> SYS1TO8:6*VTHN:(CA.CA.CA)
N= 27 OUT OF 41 69.CMPGTETW VS. 1.FTPHC



TER PLOT <7> SYS1TO8:7*VTRN:(CA.CA.CA)
N= 39 OUT OF 89 69.CMPGTETW VS. 1.FTPHC



SCATTER PLOT <8> SYS1T08:8*VTRN:(CA,CA,CA)
N= 17 OUT OF 42 69.CMPGTETW VS. 1.FTPHC



```
.TTER PLOT  <9> SYS1T08:1•VTRN:(CM,CM,CM)
          N= 40 OUT OF 85  69.CMPGTETW VS. 1.FTPHC
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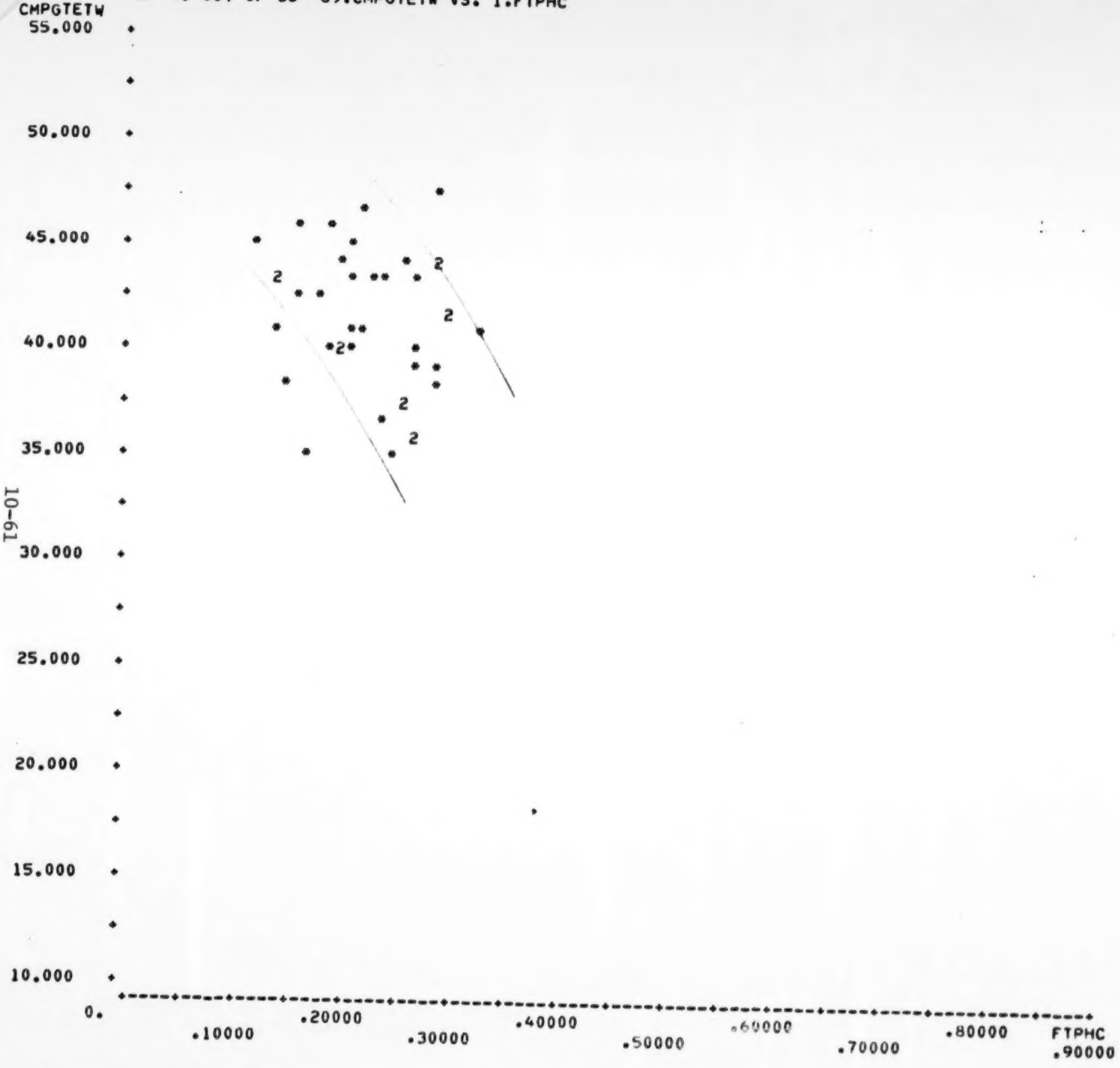

```
SCATTER PLOT  <11> SYS1T08:3*VTRN:(CM,CM,CM)
          N= 35 OUT OF 72  69.CMPGTETW VS. 1.FTPHC
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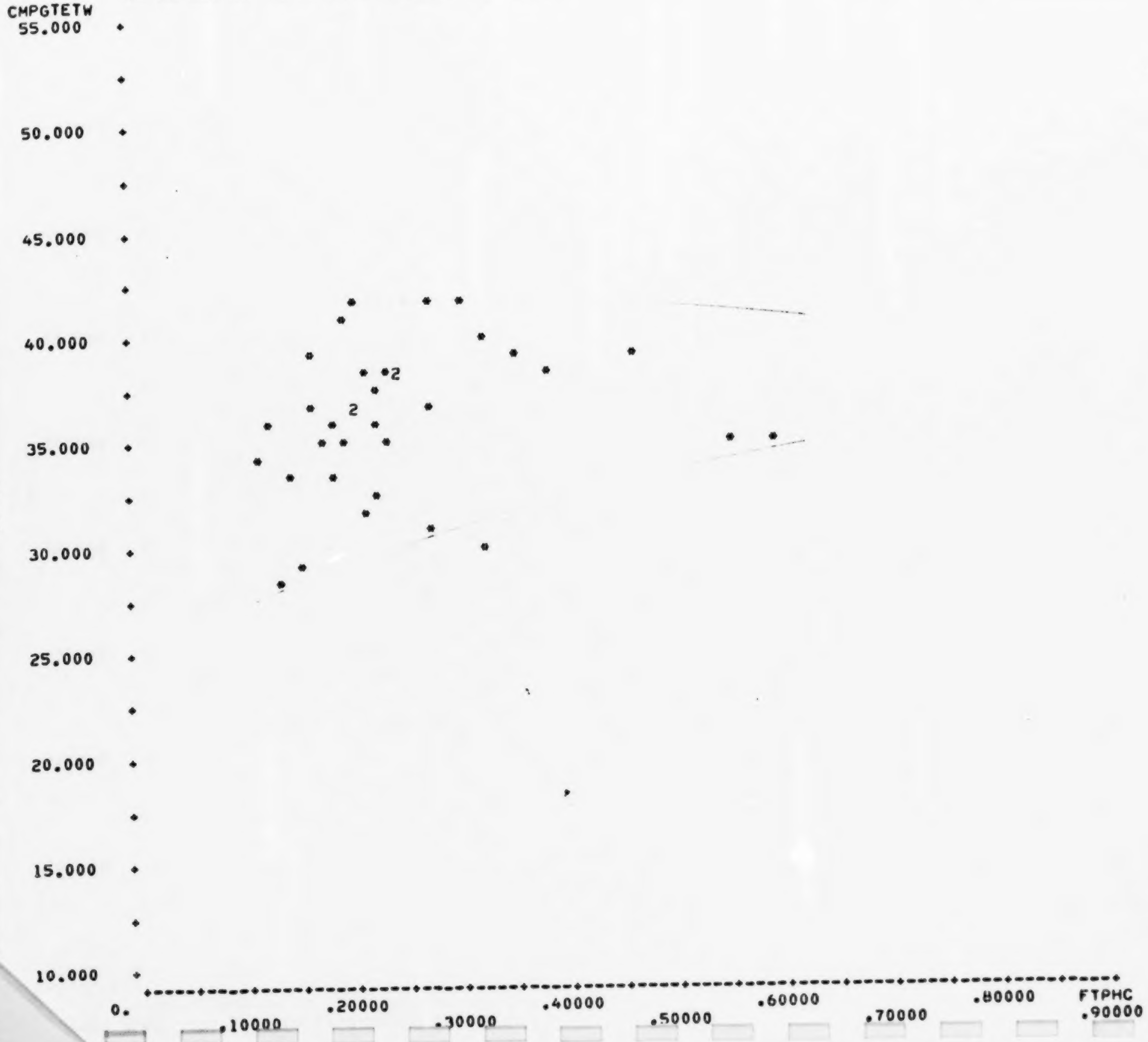
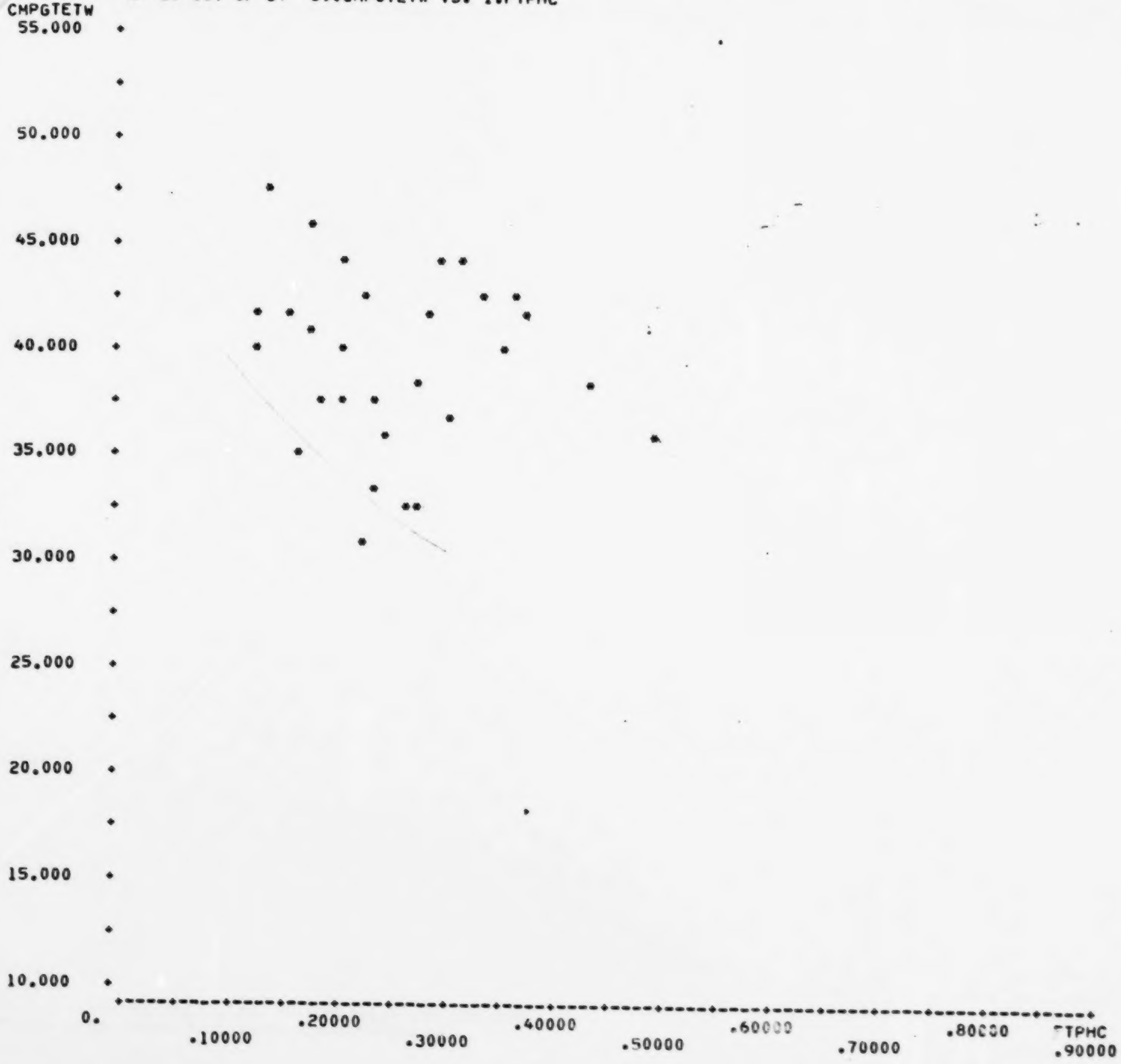
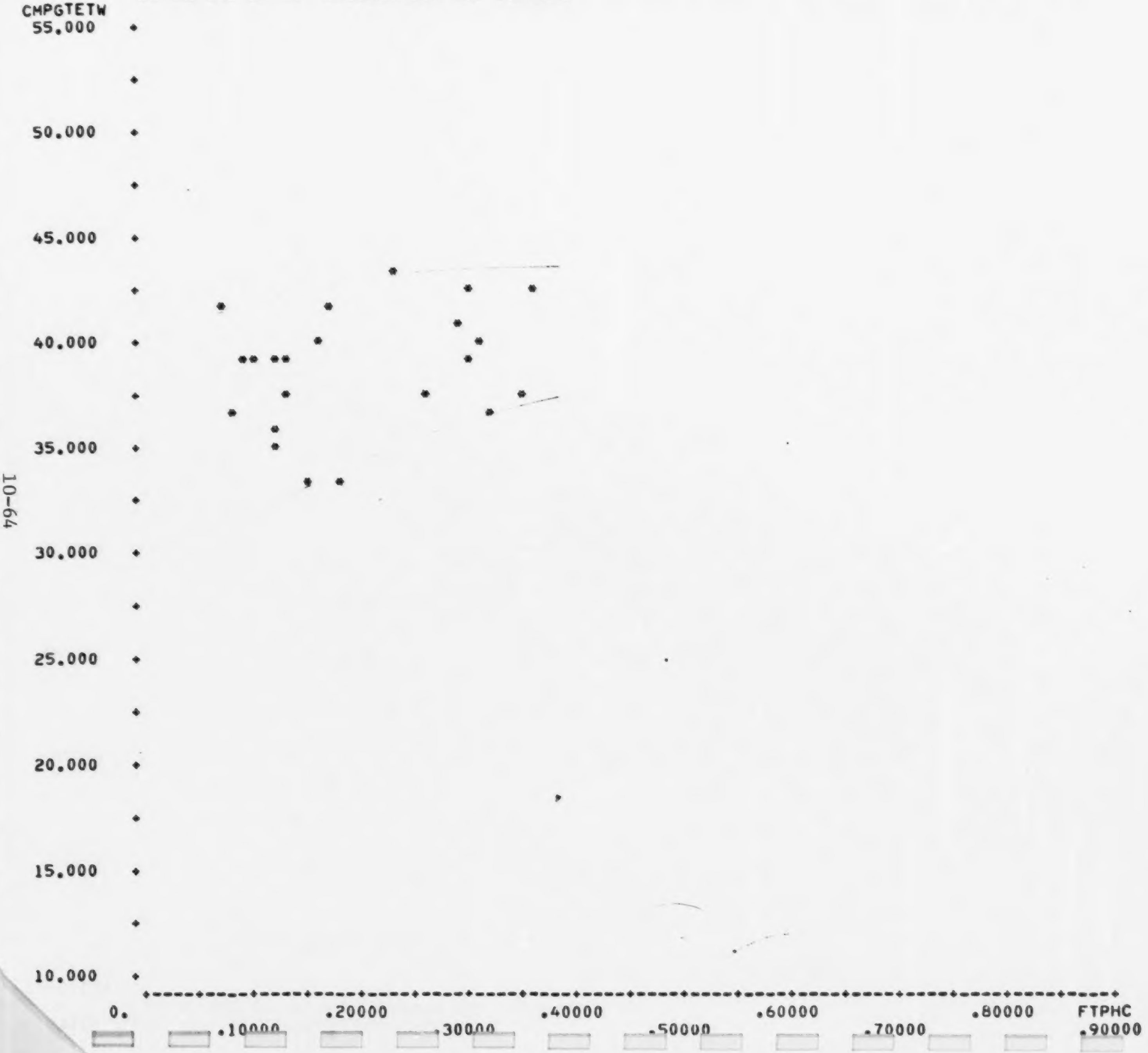


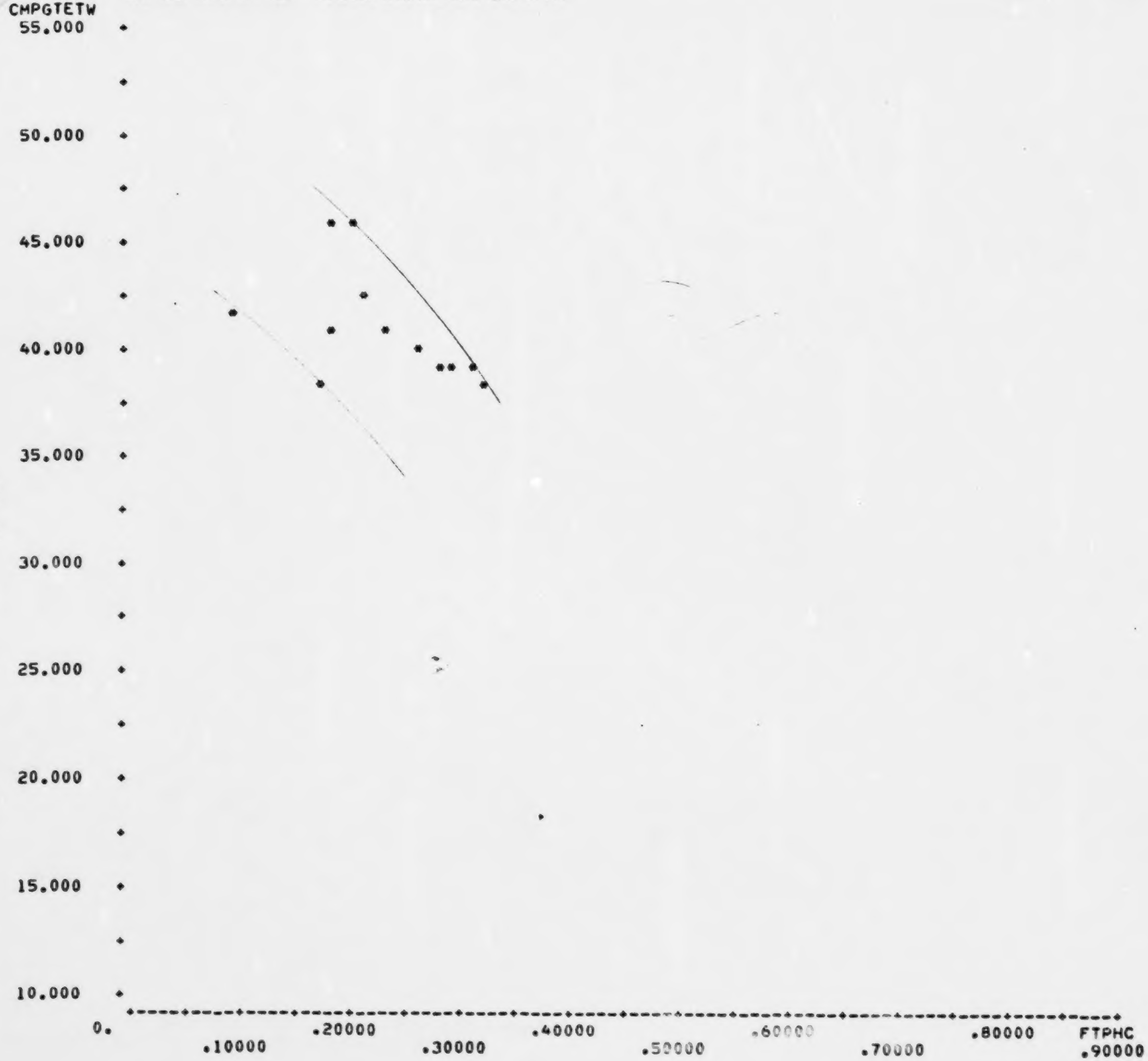
TTER PLOT <12> SYS1T08:4*VTRN:(CM.CM.CM)
N= 29 OUT OF 57 69.CMPGTETW VS. 1.FTPHC



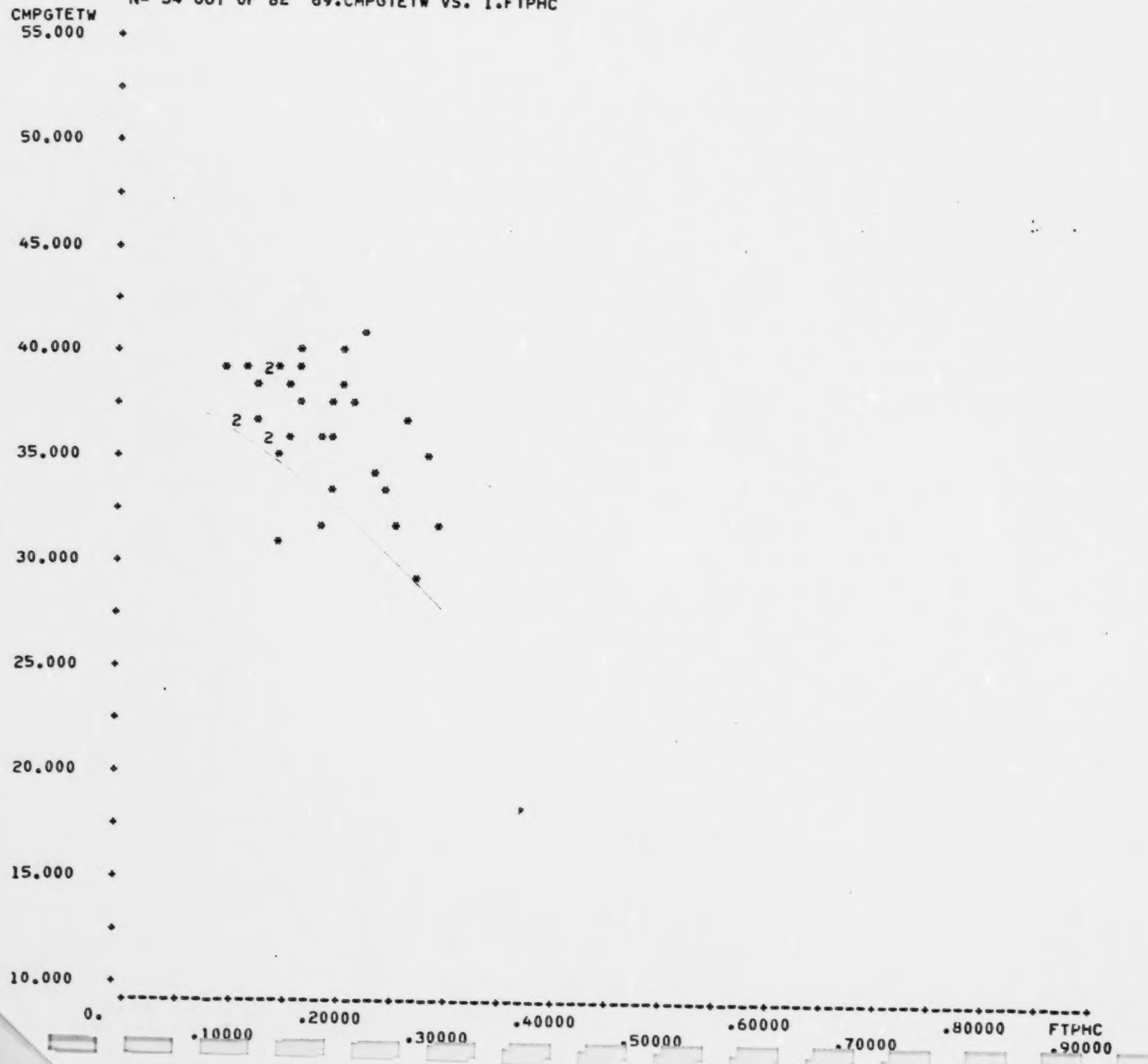
SCATTER PLOT <13> SYS1TO8:5•VTRN:(CM•CM•CM)
N= 22 OUT OF 46 69.CMPGTETW VS. 1.FTPHC



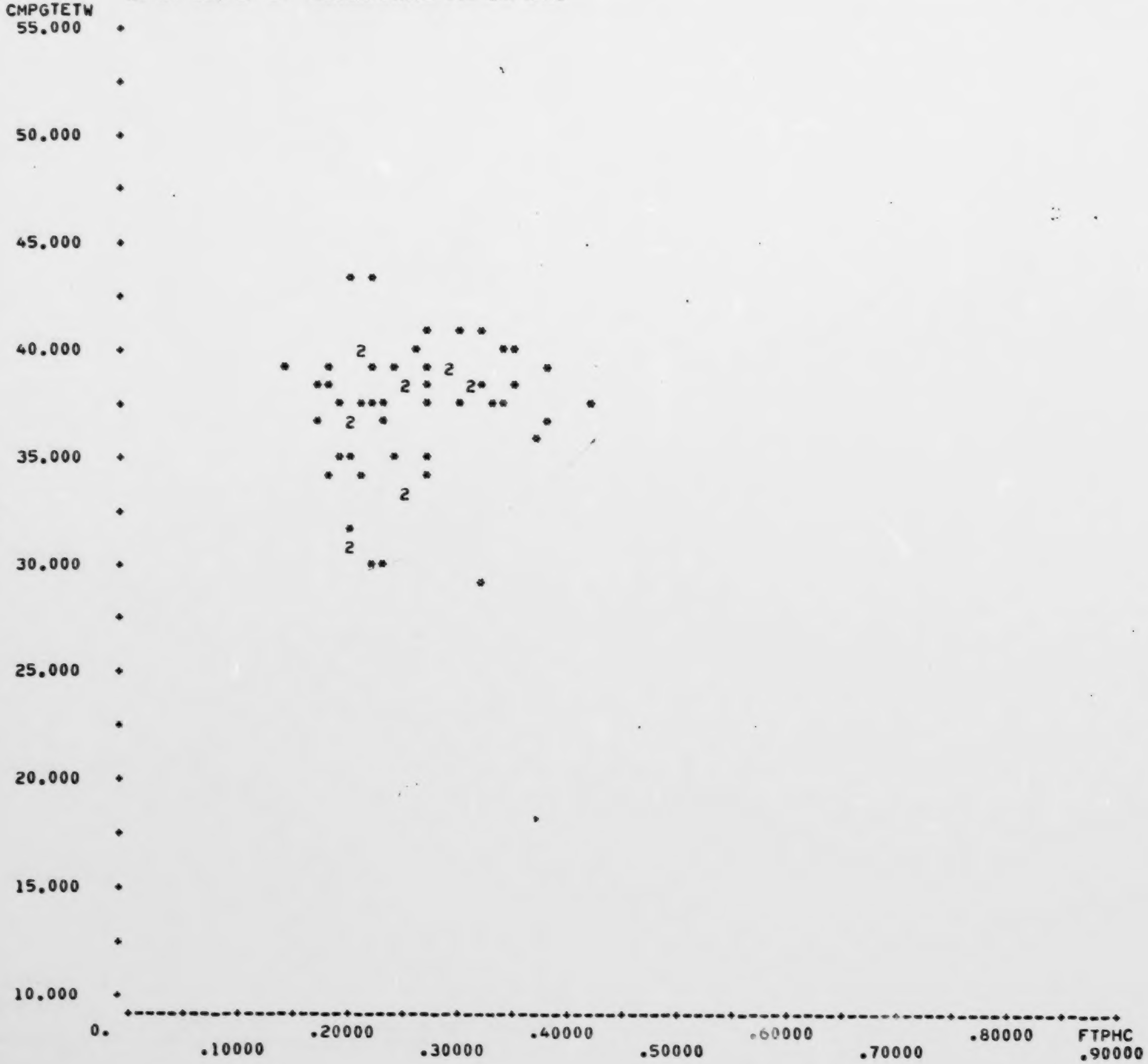
ATTER PLOT <14> SYS1T08:6*VTRN:(CM.CM.CM)
N= 12 OUT OF 36 69.CMPGTETW VS. 1.FTPHC



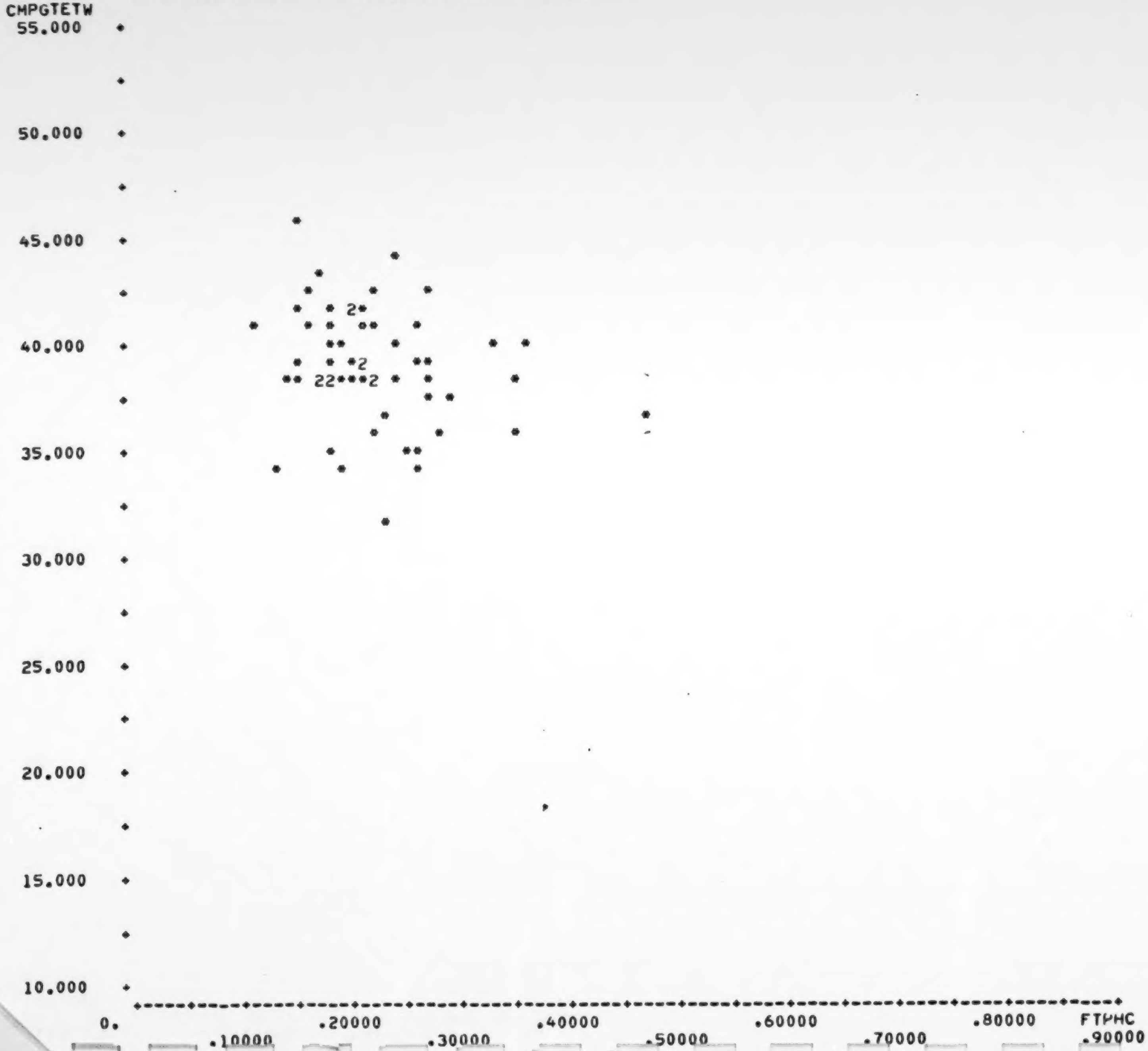
SCATTER PLOT <15> SYS1T08:7*VTRN:(CM,CM,CM)
N= 34 OUT OF 82 69.CMPGTETW VS. 1.FTPHC



ATTER PLOT <19> SYS1T08:3*VTRN:(LA,LA)
N= 57 OUT OF 87 69.CMPGTETW VS. 1.FTPHC



SCATTER PLOT <20> SYS1T08:4*VTRN:(LA.LA)
N= 57 OUT OF 114 69.CMPGTETW VS. 1.FTPHC



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CATTER PLOT  <21> SYS1T08:5*VTRN:(LA.LA)
          N= 12 OUT OF 30  69.CMPGTETW VS. 1.FTPHC
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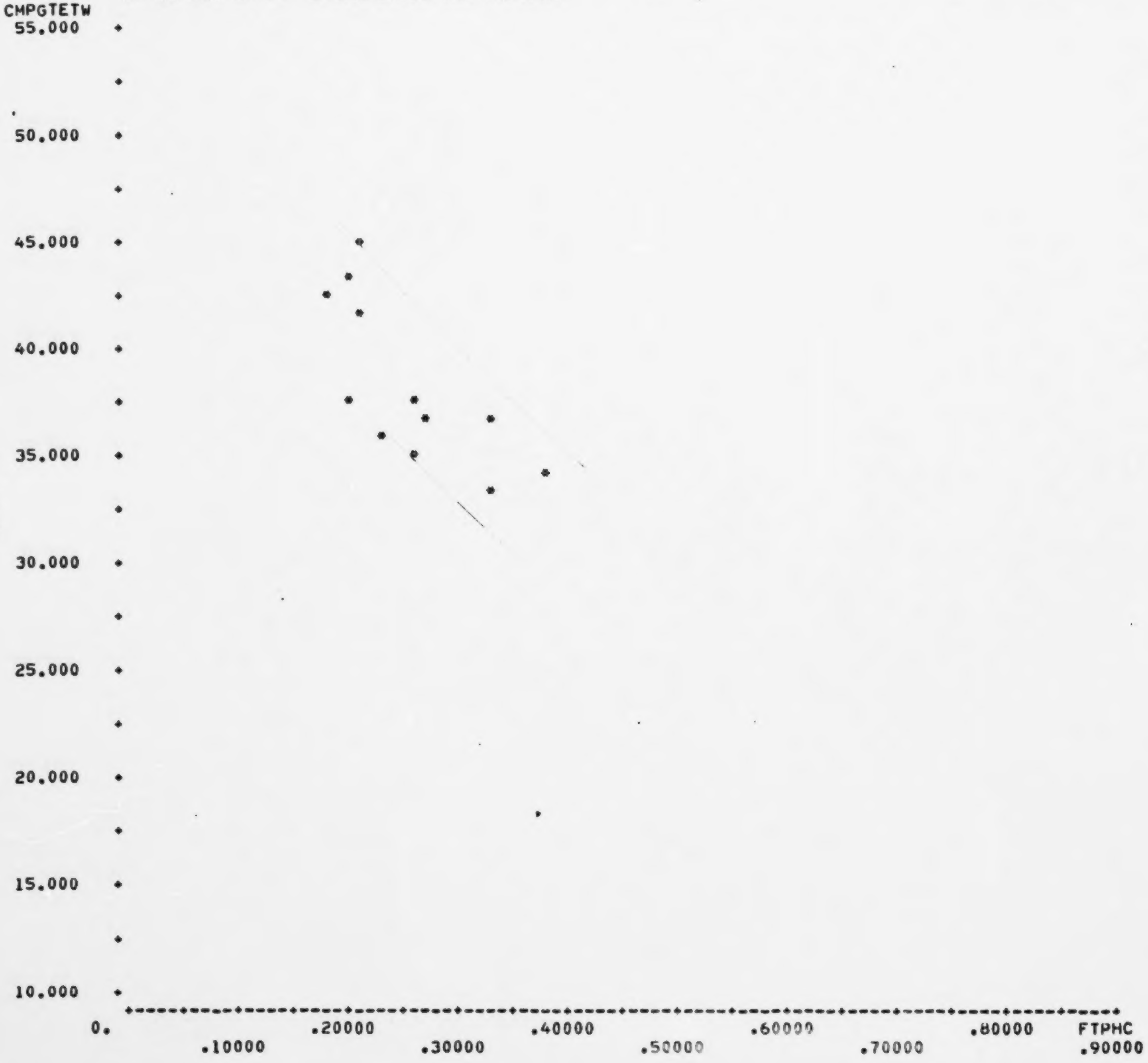

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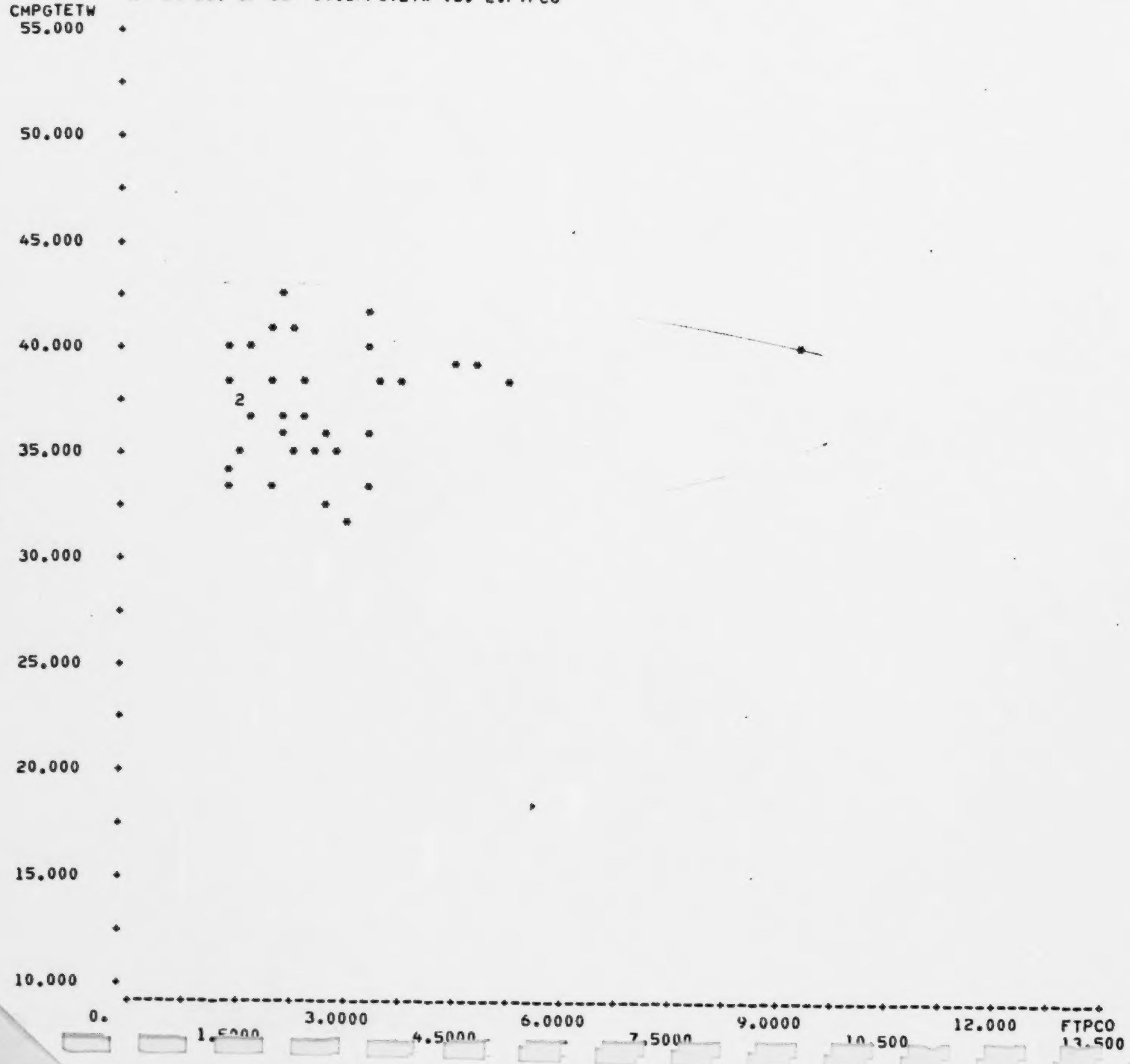
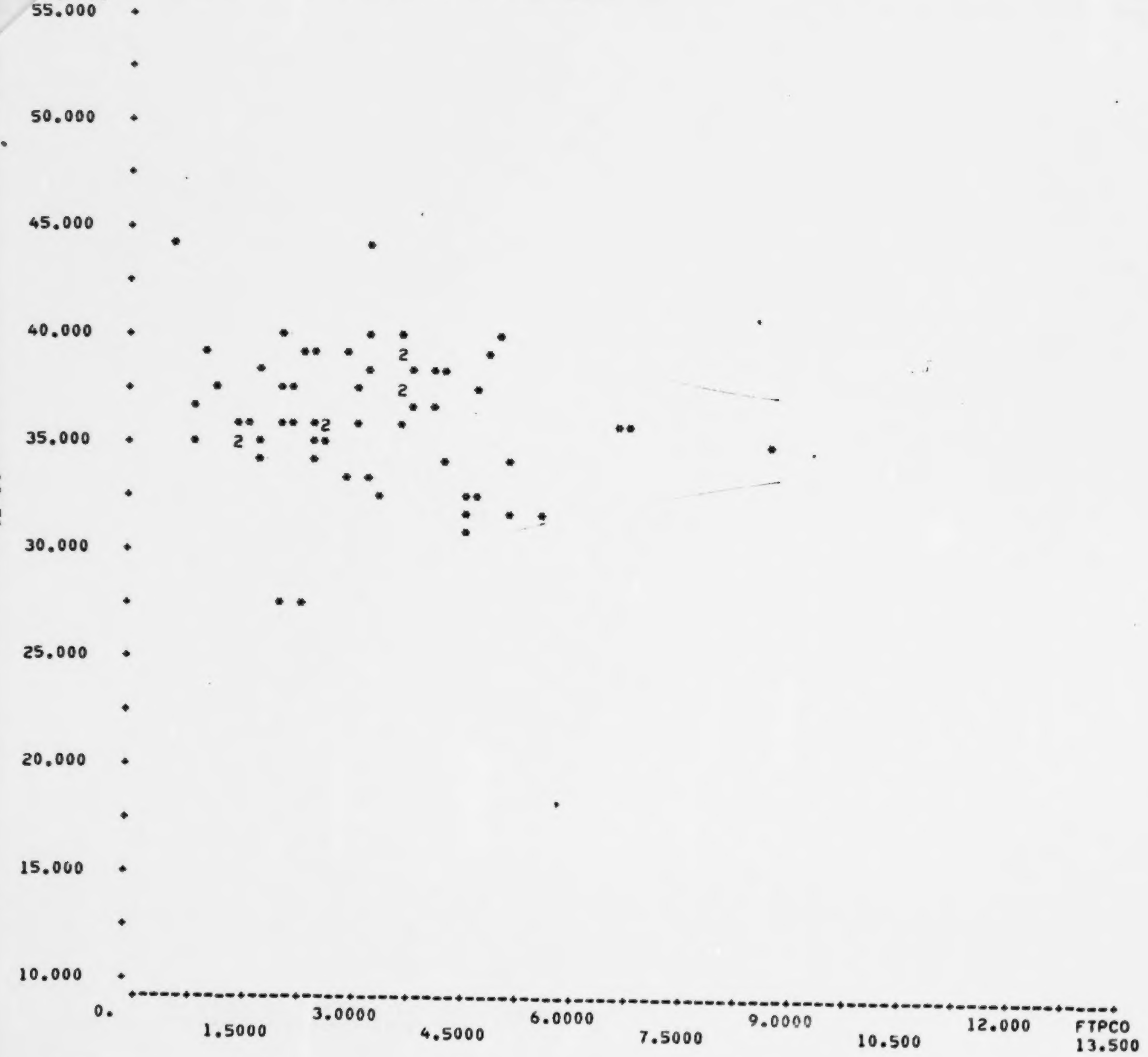
<SCATTER  BYST VAR=69!2 STRAT=V102*V28!(1,6,8),(2,3,4),(7,9) INTERVAL=(10.,55.)!(0.,13.5)>

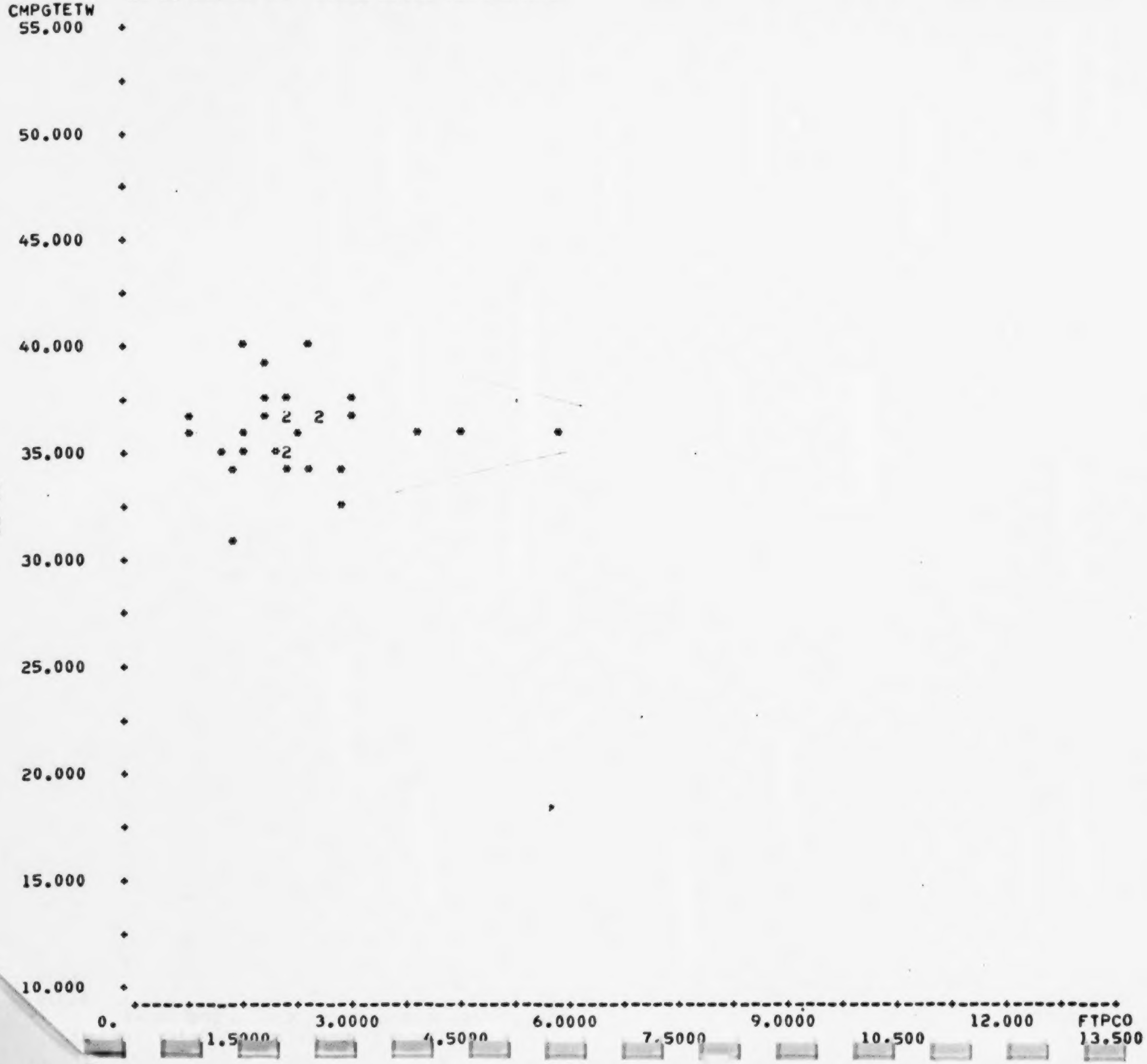
SCATTER PLOT  <1> SYS1T08!1*VTRN!(CA,CA,CA)
          N= 34 OUT OF 63  69.CMPGTETW VS. 2.FTPCO
```



```
R PLOT  <3> SYSIT08:3*VTRN:(CA,CA,CA)
      N= 61 OUT OF 125  69.CMPGTETW VS. 2.FTPCO
```



SCATTER PLOT <4> SYS1TO8:4*VTRN:(CA.CA.CA)
N= 30 OUT OF 61 69.CMPGTETW VS. 2.FTPCO



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TTER PLOT  <5> SYS1T08:5*VTRN:(CA,CA,CA)
           N= 51 OUT OF 79  69.CMPGTETW VS. 2.FTPCO
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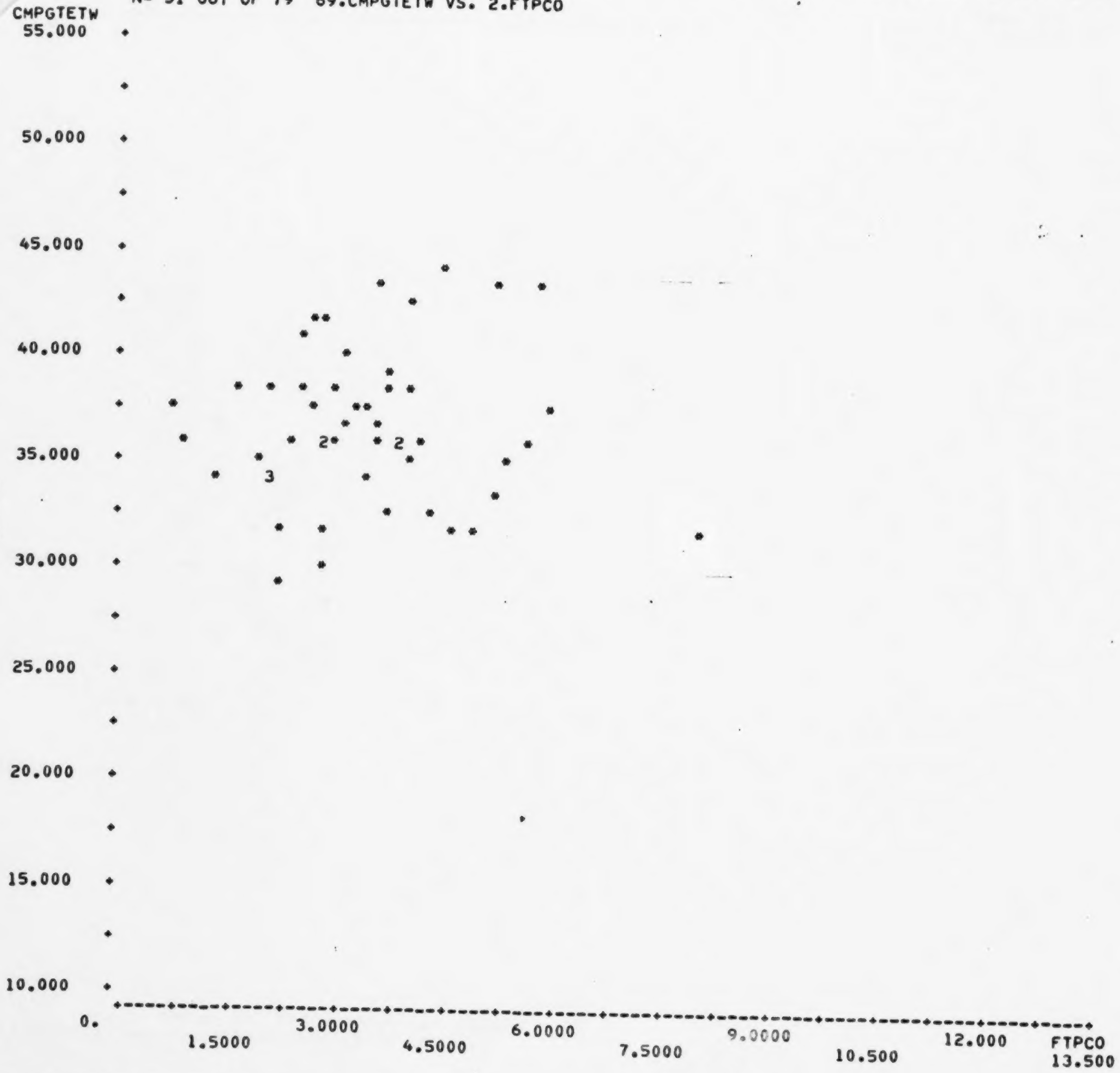
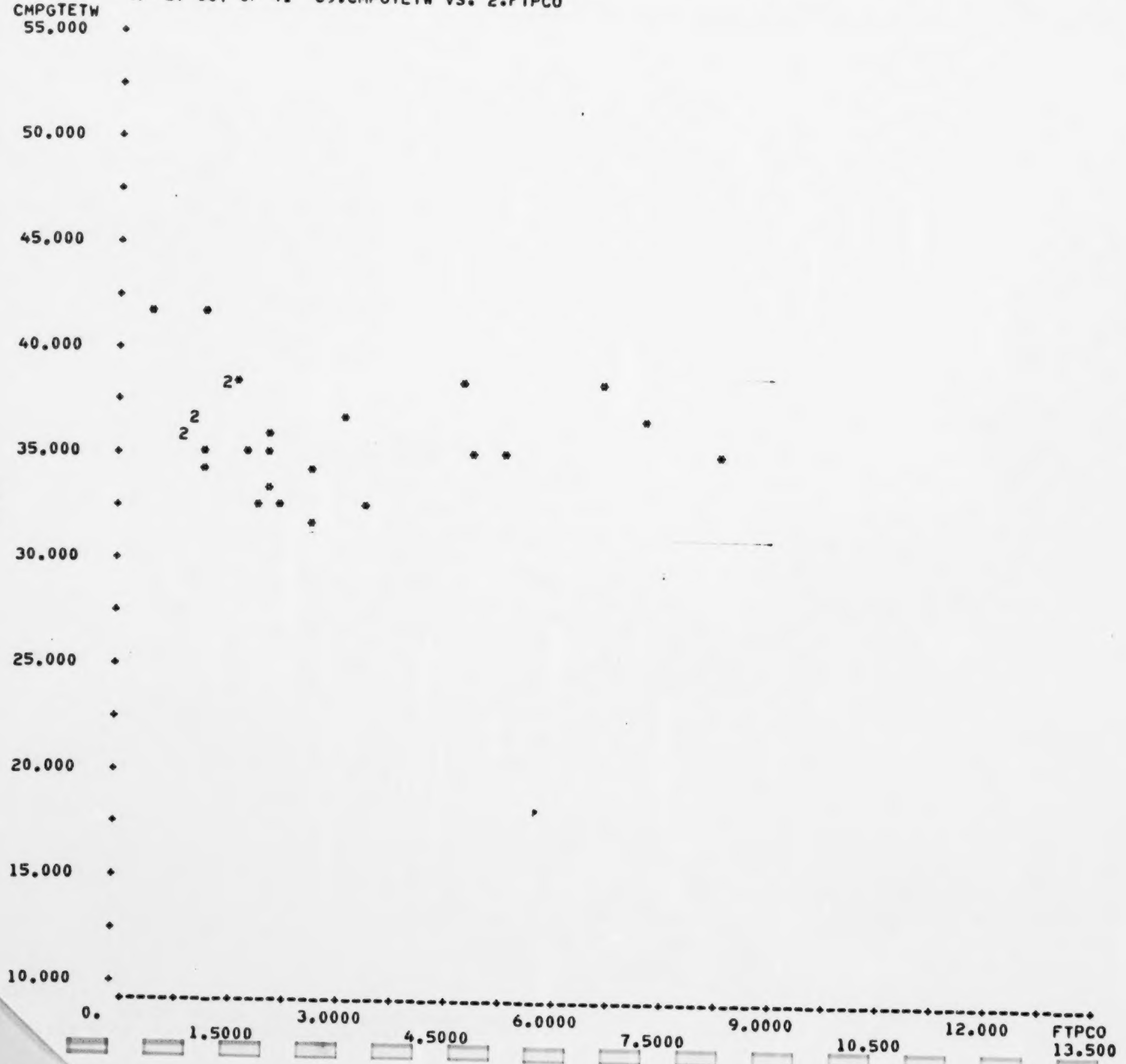
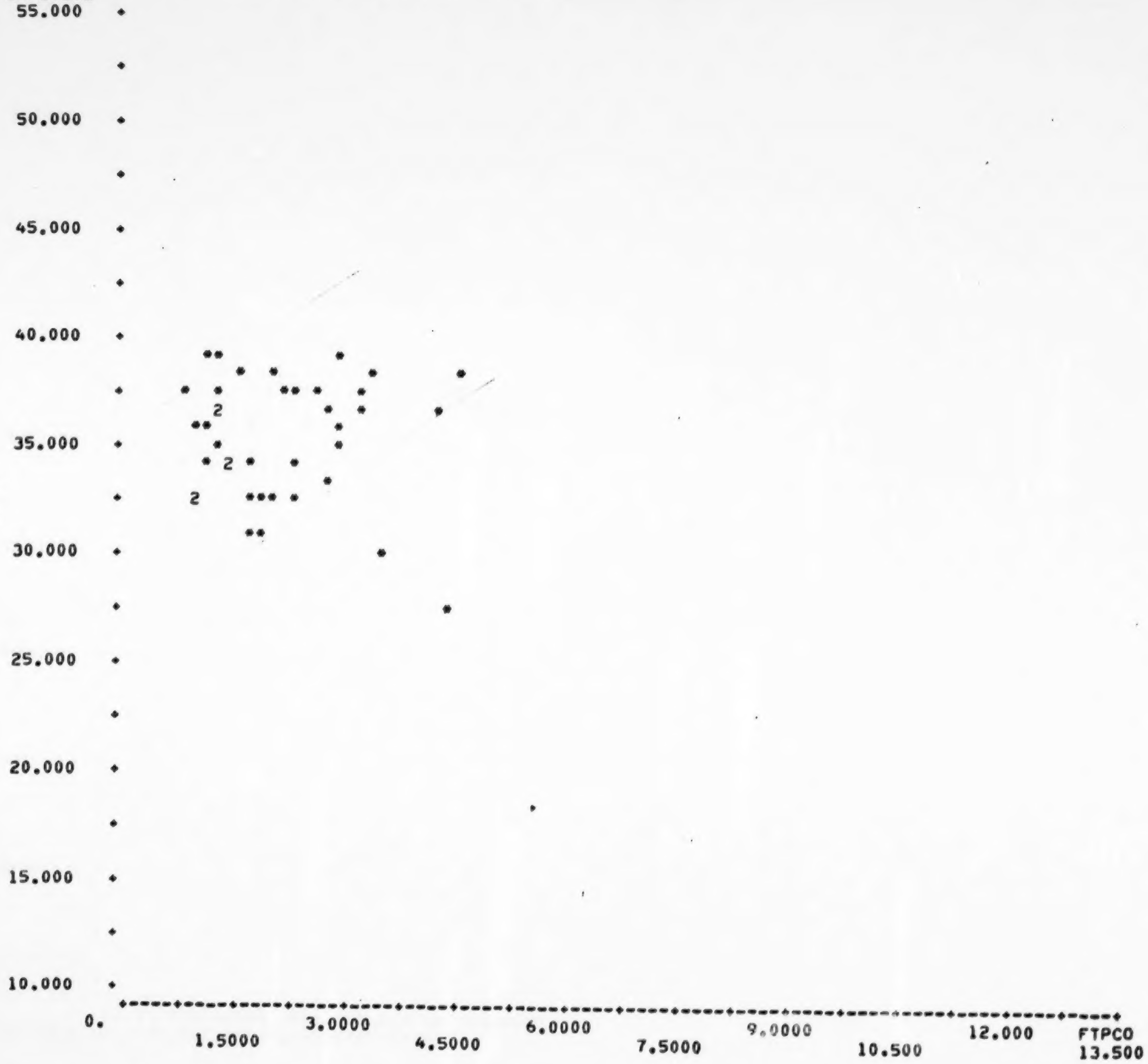


```
SCATTER PLOT  <6> SYS1TO8:6*VTRN:(CA.CA.CA)
           N= 27 OUT OF 41  69.CMPGTETW VS. 2.FTPCO
```



ATTER PLOT <7> SYS1T08:7*VTRN:(CA,CA,CA)
N= 39 OUT OF 89 69.CMPGTETW VS. 2.FTPCO



```
SCATTER PLOT  <B> SYS1T08:8*VTRN:(CA.CA.CA)
          N= 17 OUT OF 42  69.CMPGTETW VS. 2.FTPCO
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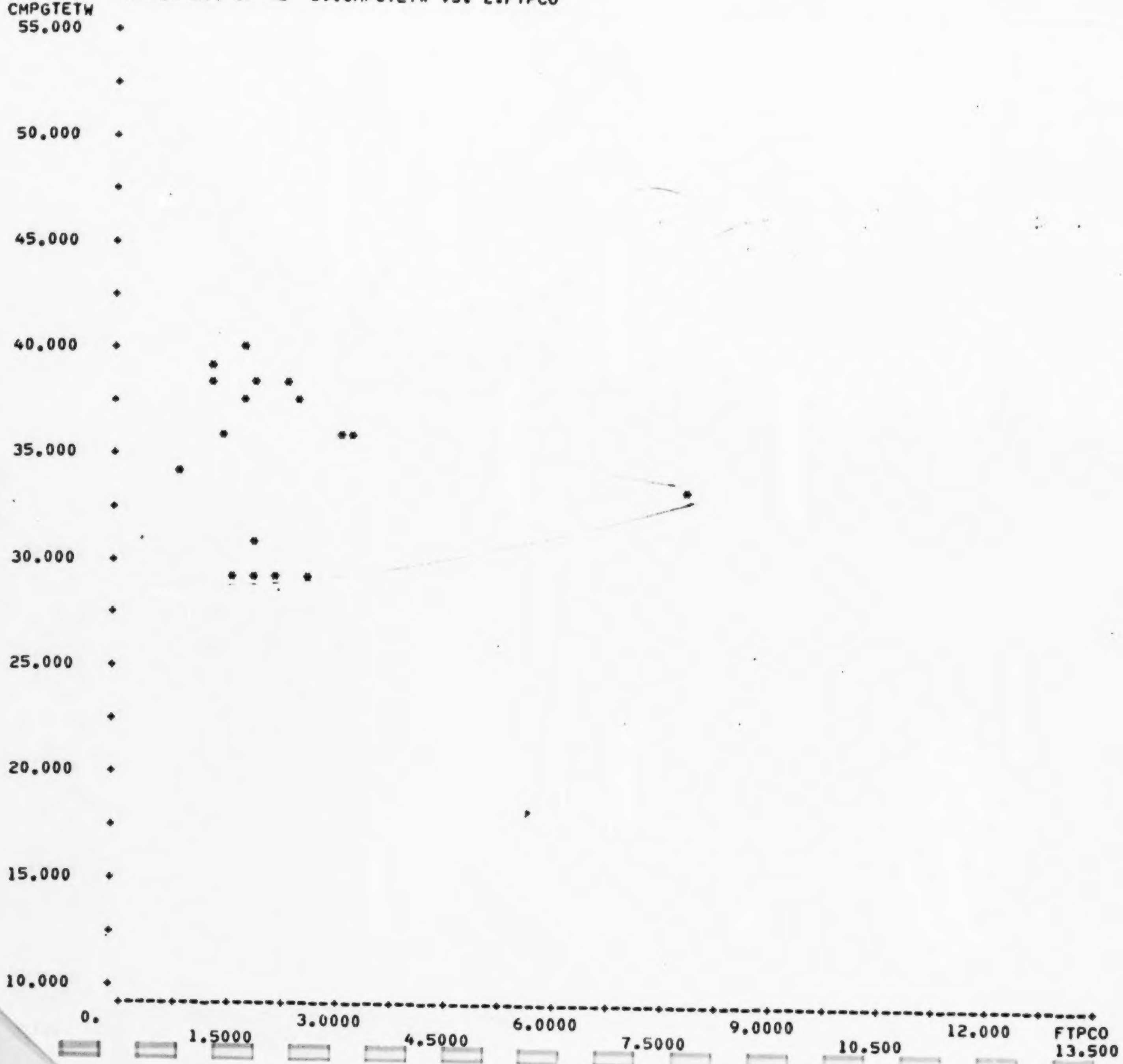
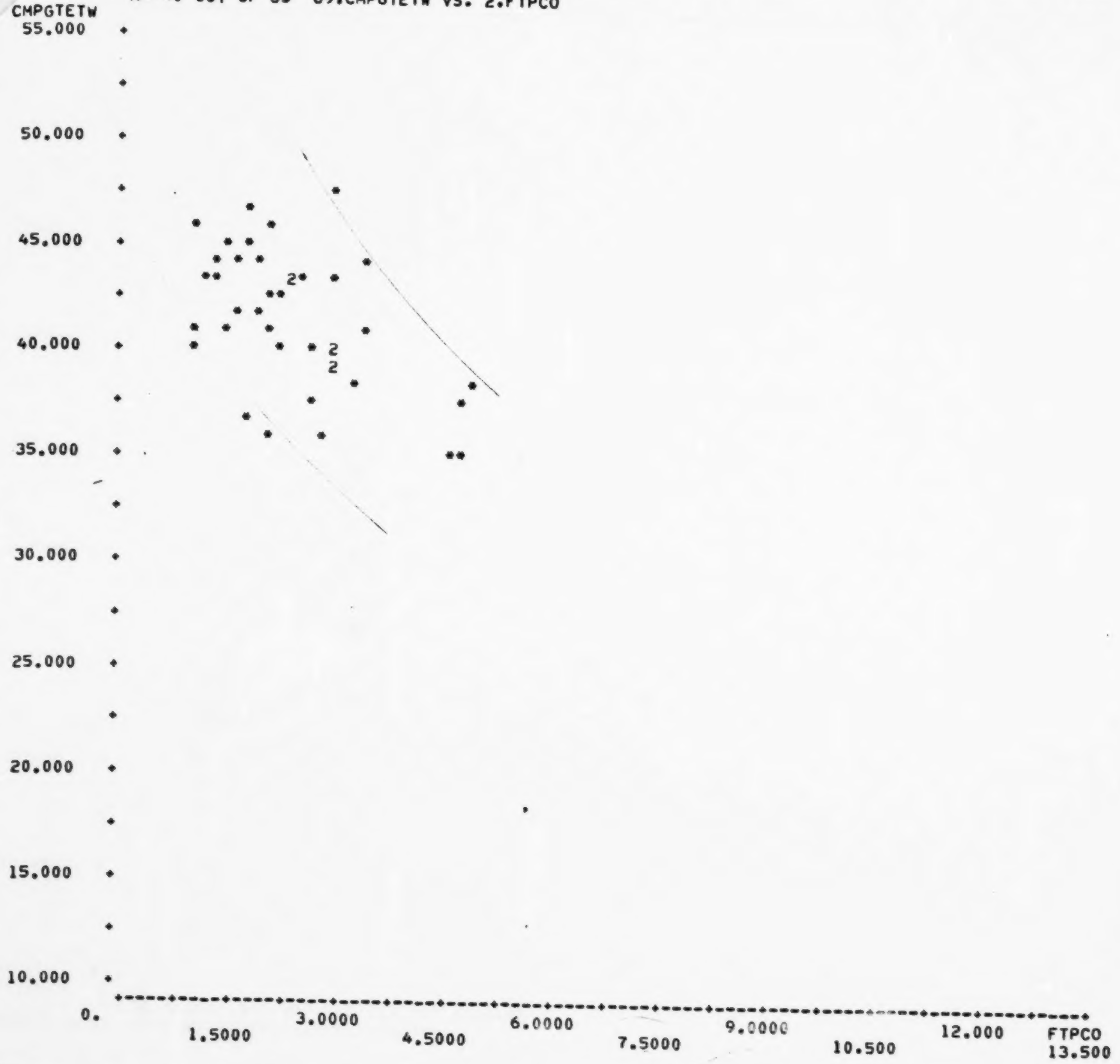
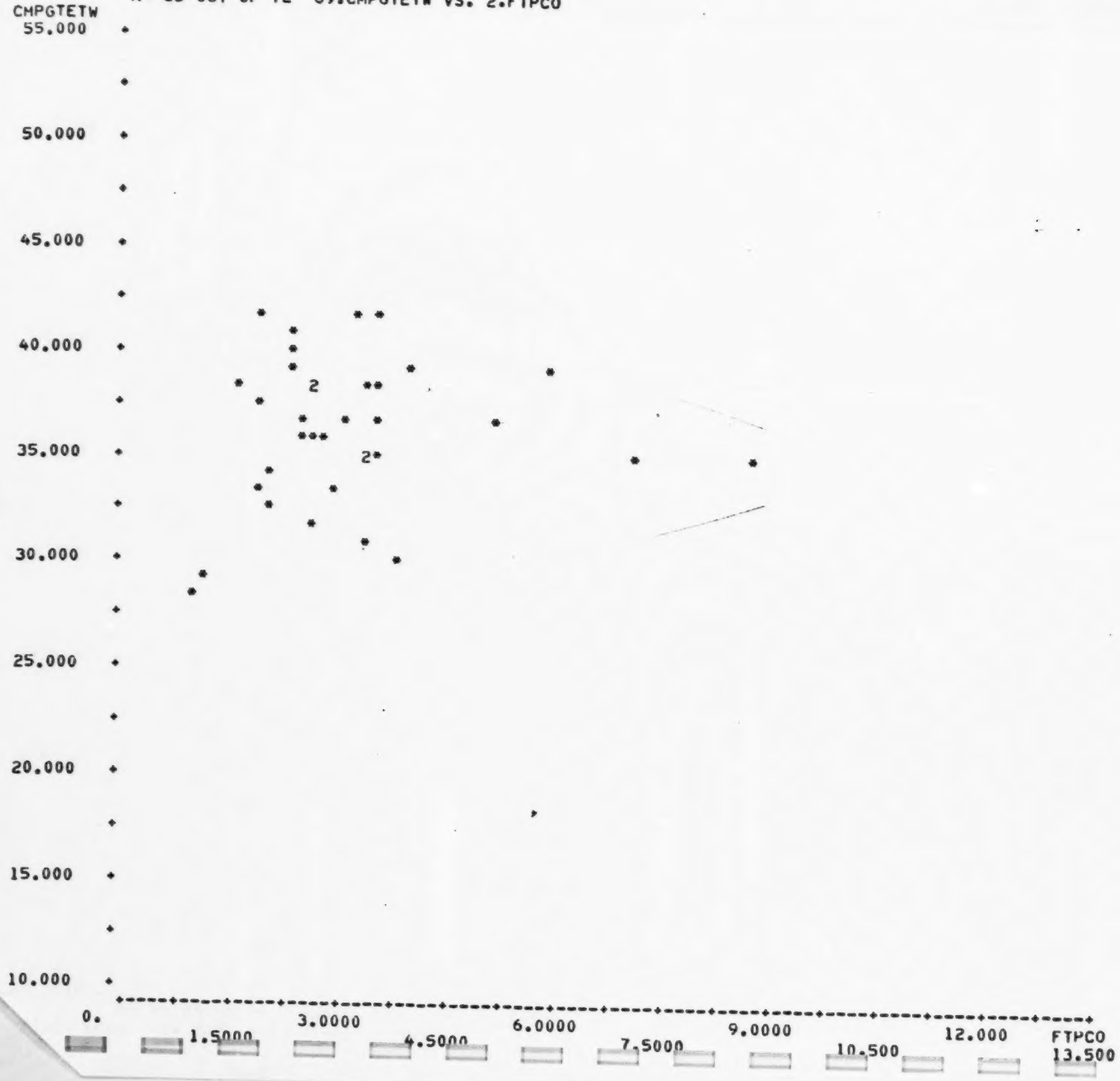


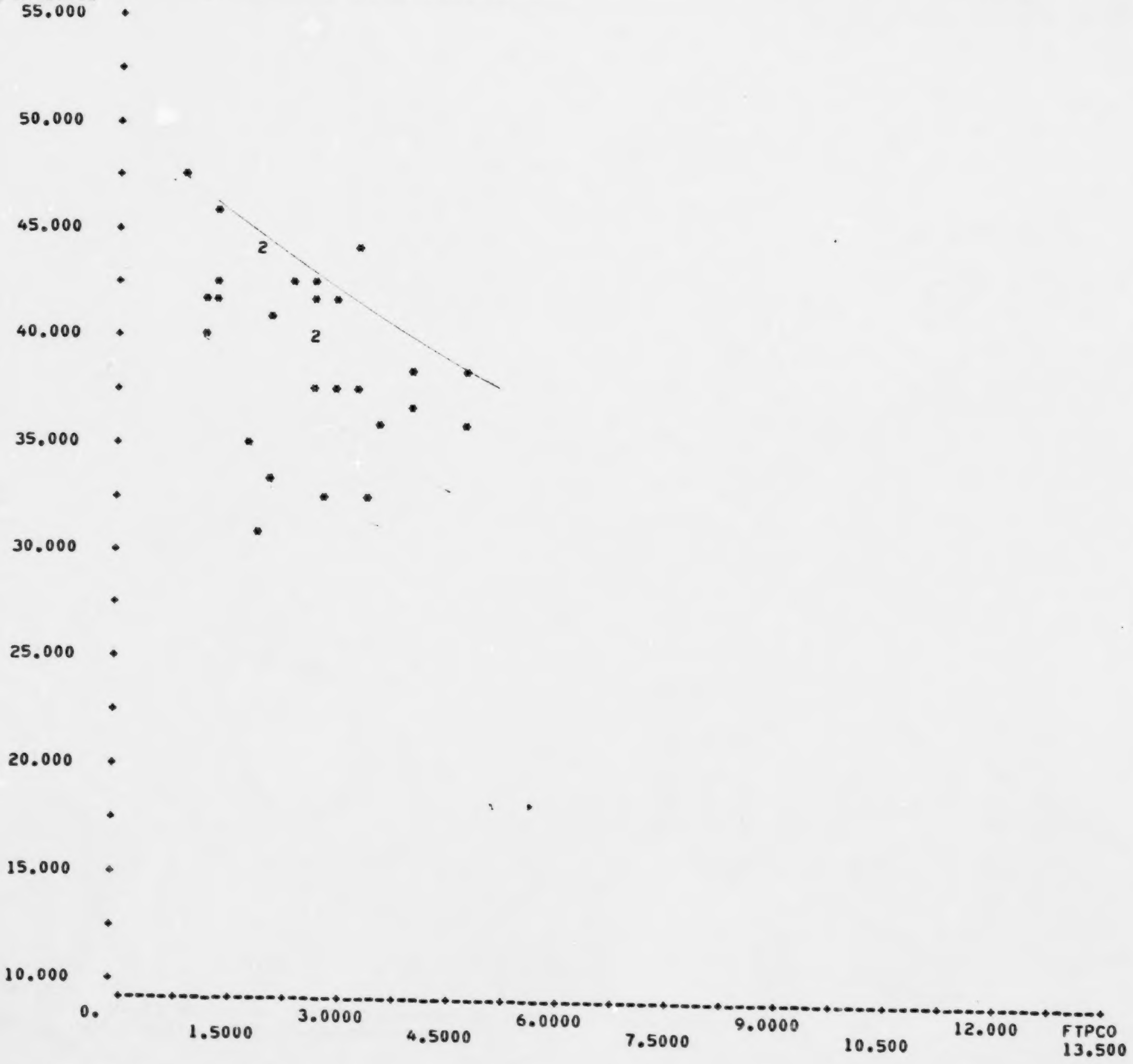
TTER PLOT <9> SYS1TO8:1*VTHN:(CM,CM,CM)
N= 40 OUT OF 85 69.CMPGTETW VS. 2.FTPCO



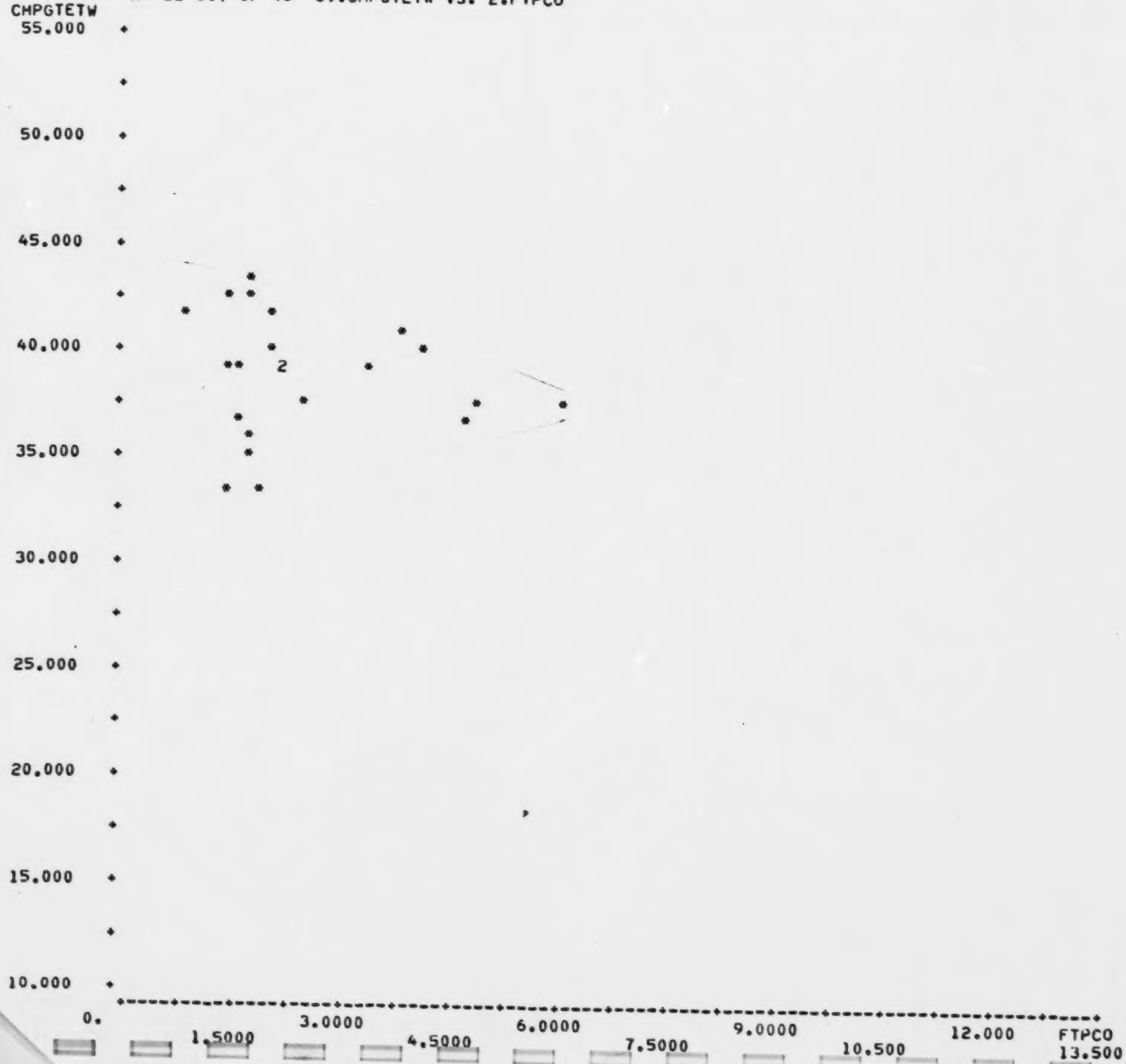
SCATTER PLOT <11> SYS1T08:3*VTRN:(CM,CM,CM)
N= 35 OUT OF 72 69.CMPGTETW VS. 2.FTPCO



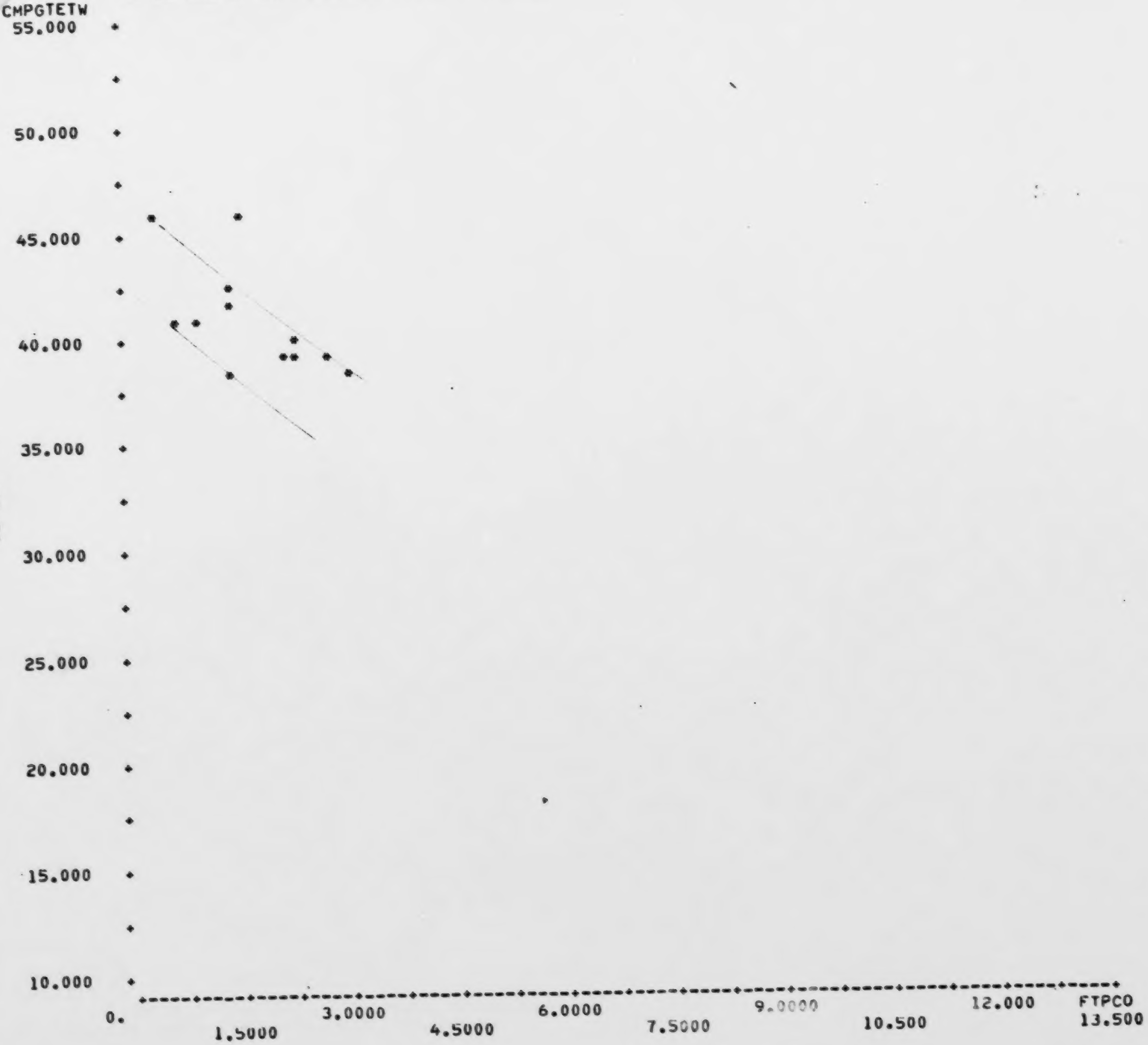
TTER PLOT <12> SYS1T08:4-VTRN1(CM,CM,CM)
N= 29 OUT OF 57 69.CMPGTETW VS. 2.FTPCO



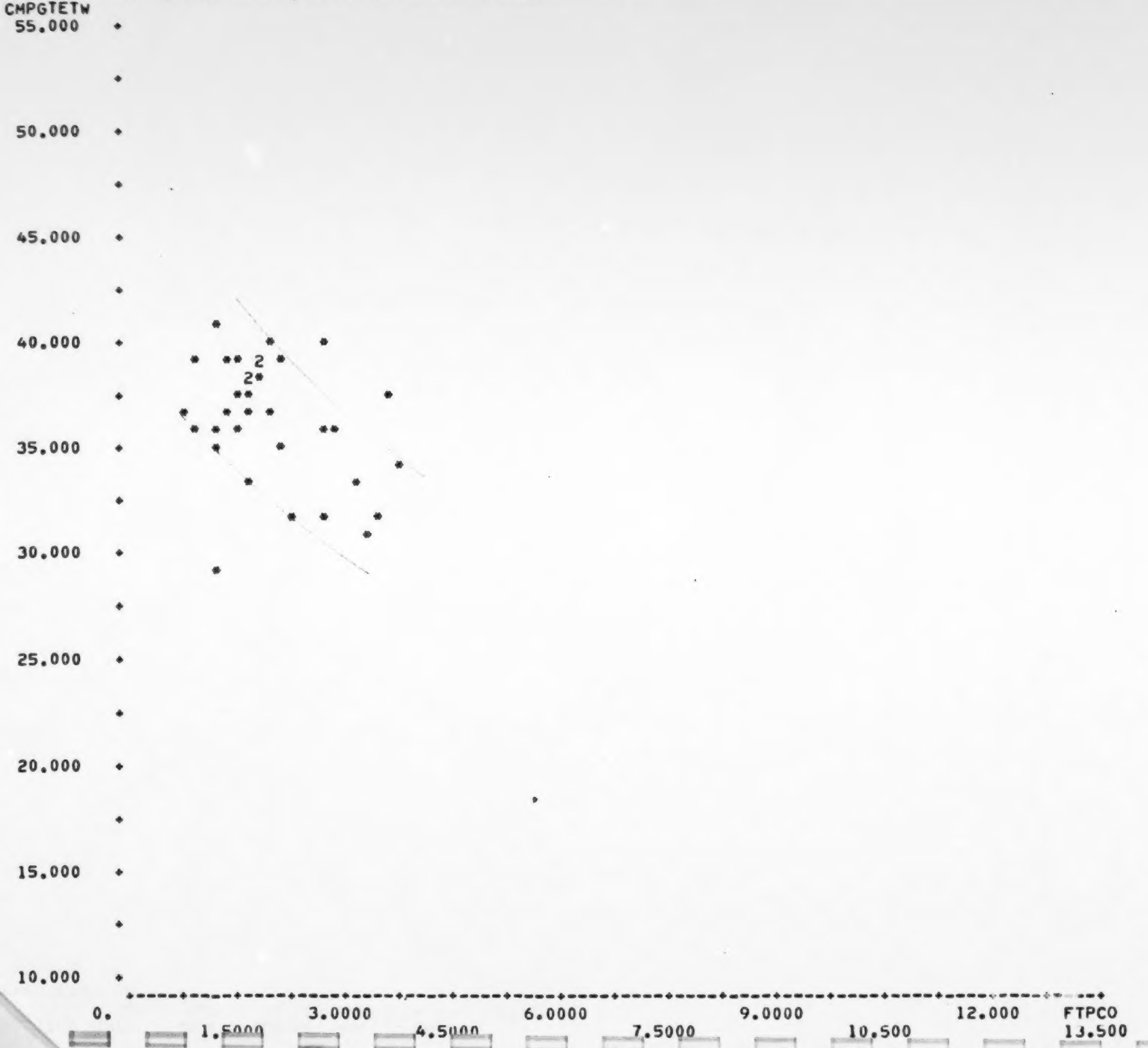
SCATTER PLOT <13> SYS1T08:5*VTRN:(CM,CM,CM)
N= 22 OUT OF 46 69.CMPGTETW VS. 2.FTPCO



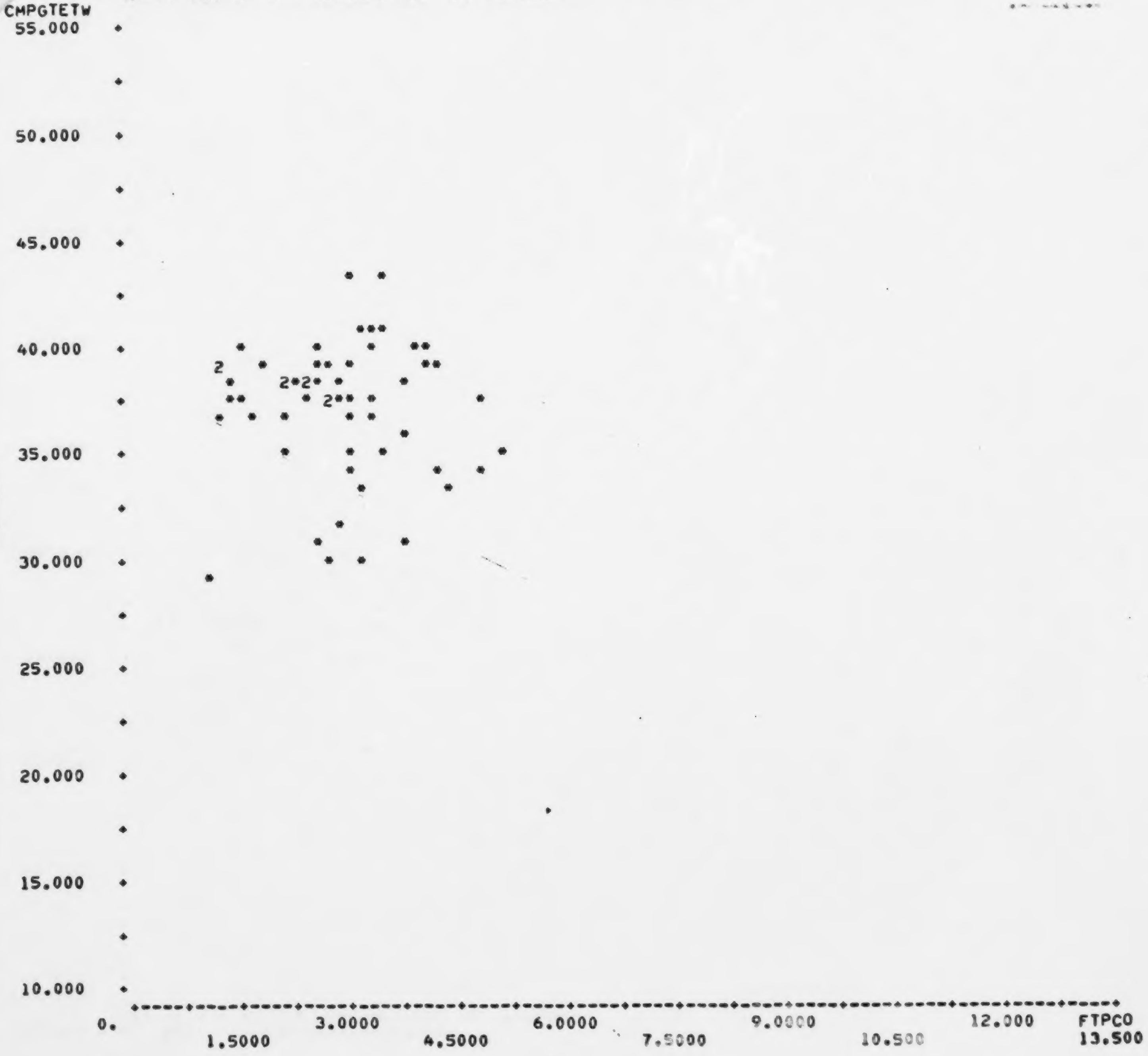
TTER PLOT <14> SYS1T08:6•VIRN:(CM•CM•CM)
N= 12 OUT OF 36 69.CMPGTETW VS. 2.FTPCO



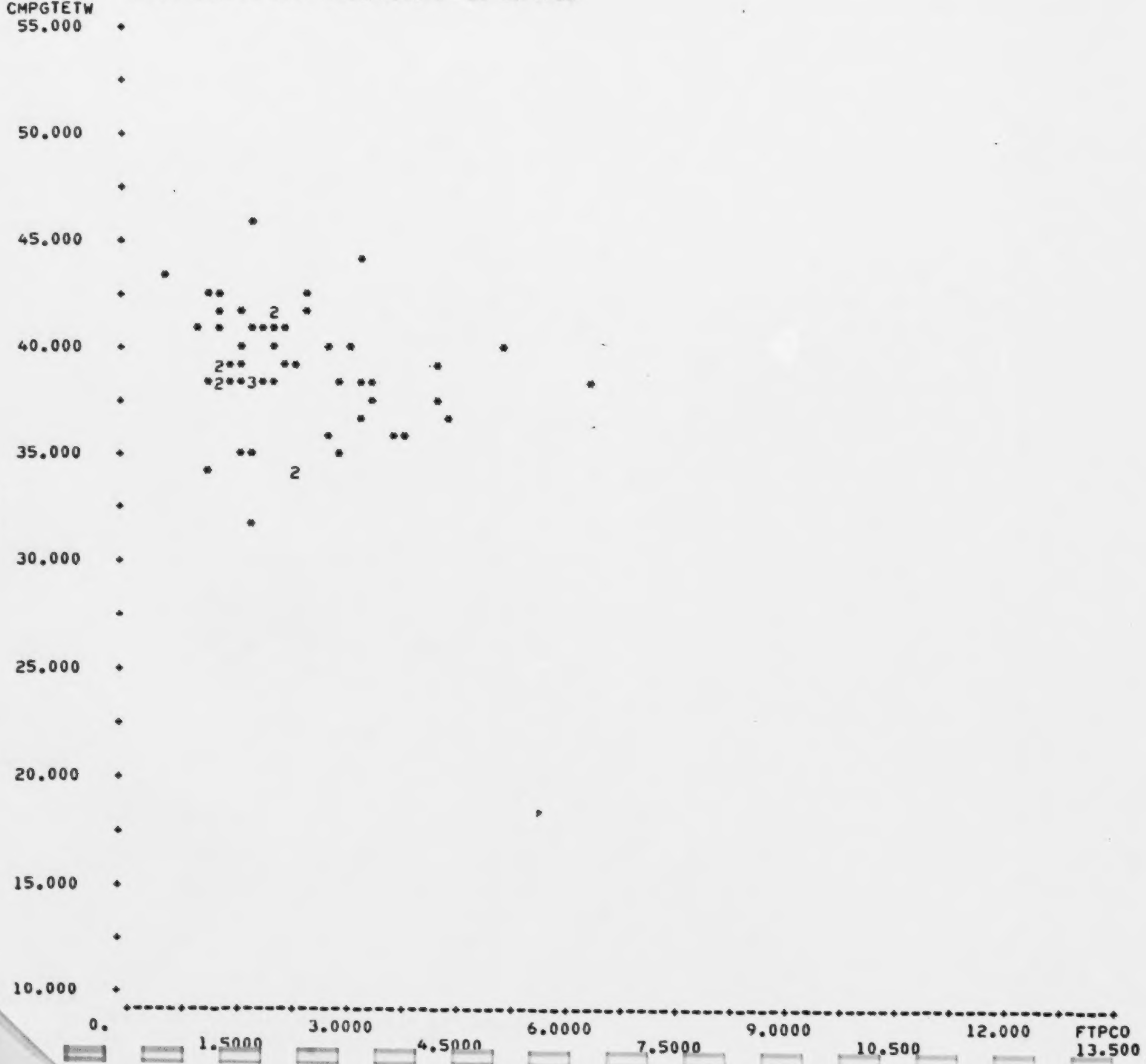
SCATTER PLOT <15> SYS1T08:7*VTRN:(CM,CM,CM)
N= 34 OUT OF 82 69.CMPGTETW VS. 2.FTPCO



TTER PLOT <19> SYS1T08:3*VTRN:(LA,LA)
N= 57 OUT OF 87 69.CMPGTETW VS. 2.FTPCO



SCATTER PLOT <20> SYS1T08:4•VTHN:(LA,LA)
N= 57 OUT OF 114 69.CMPGTETW VS. 2.FTPCO



```
TTER PLOT   <21> SYS1T08:5*VTRN:(LA,LA)
        N= 12 OUT OF 30  69.CMPGTETW VS. 2.FTPCO
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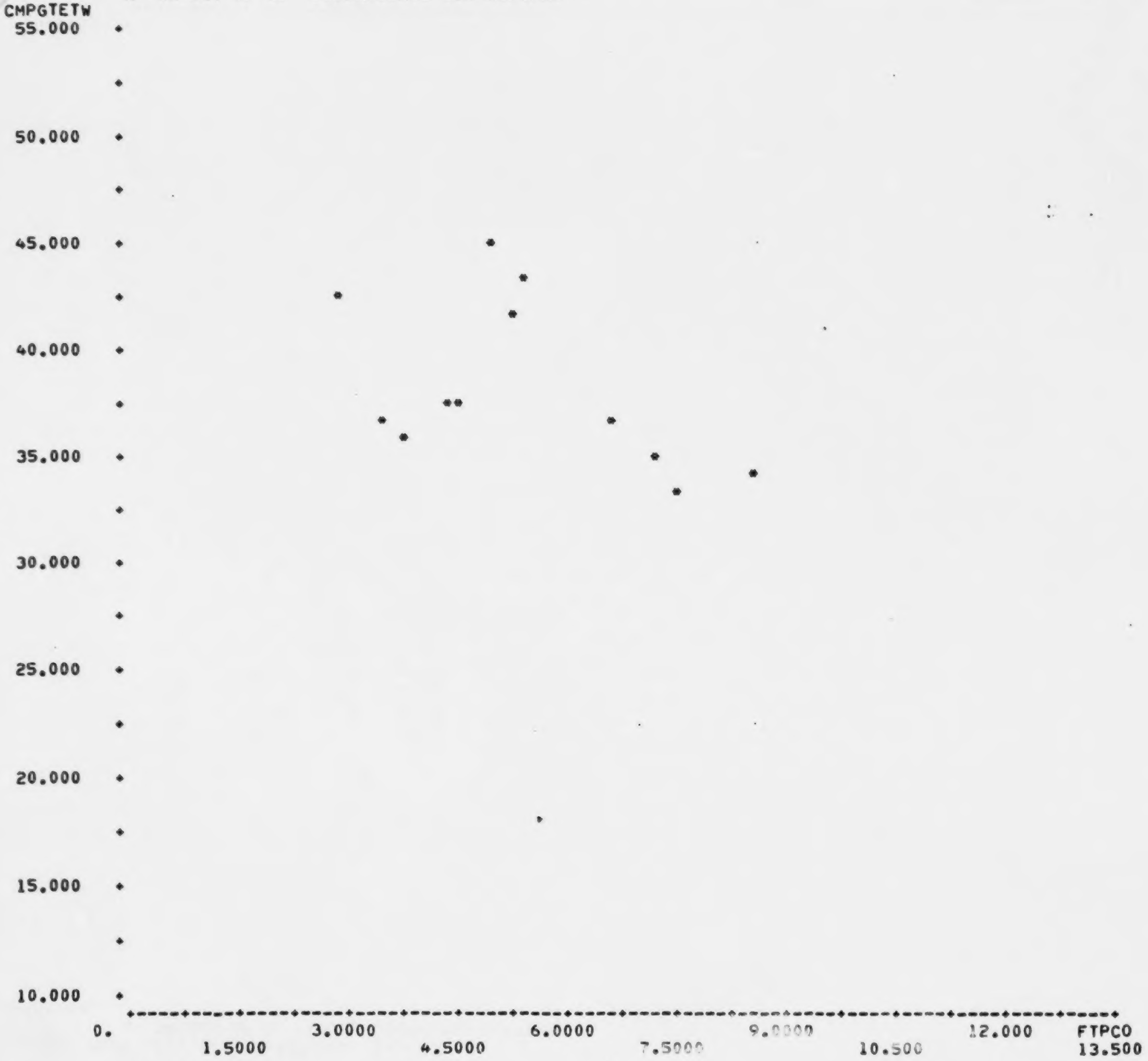
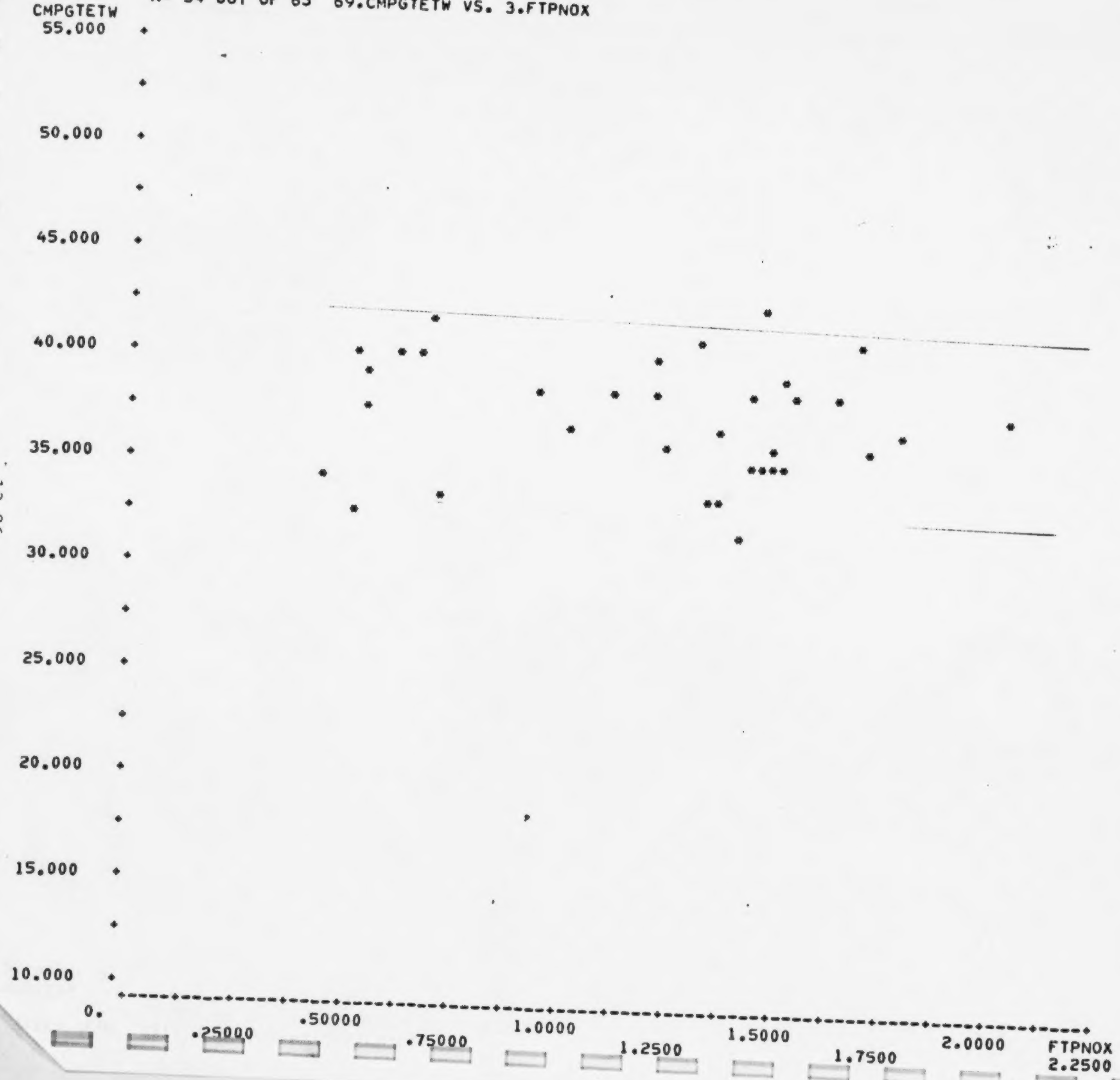
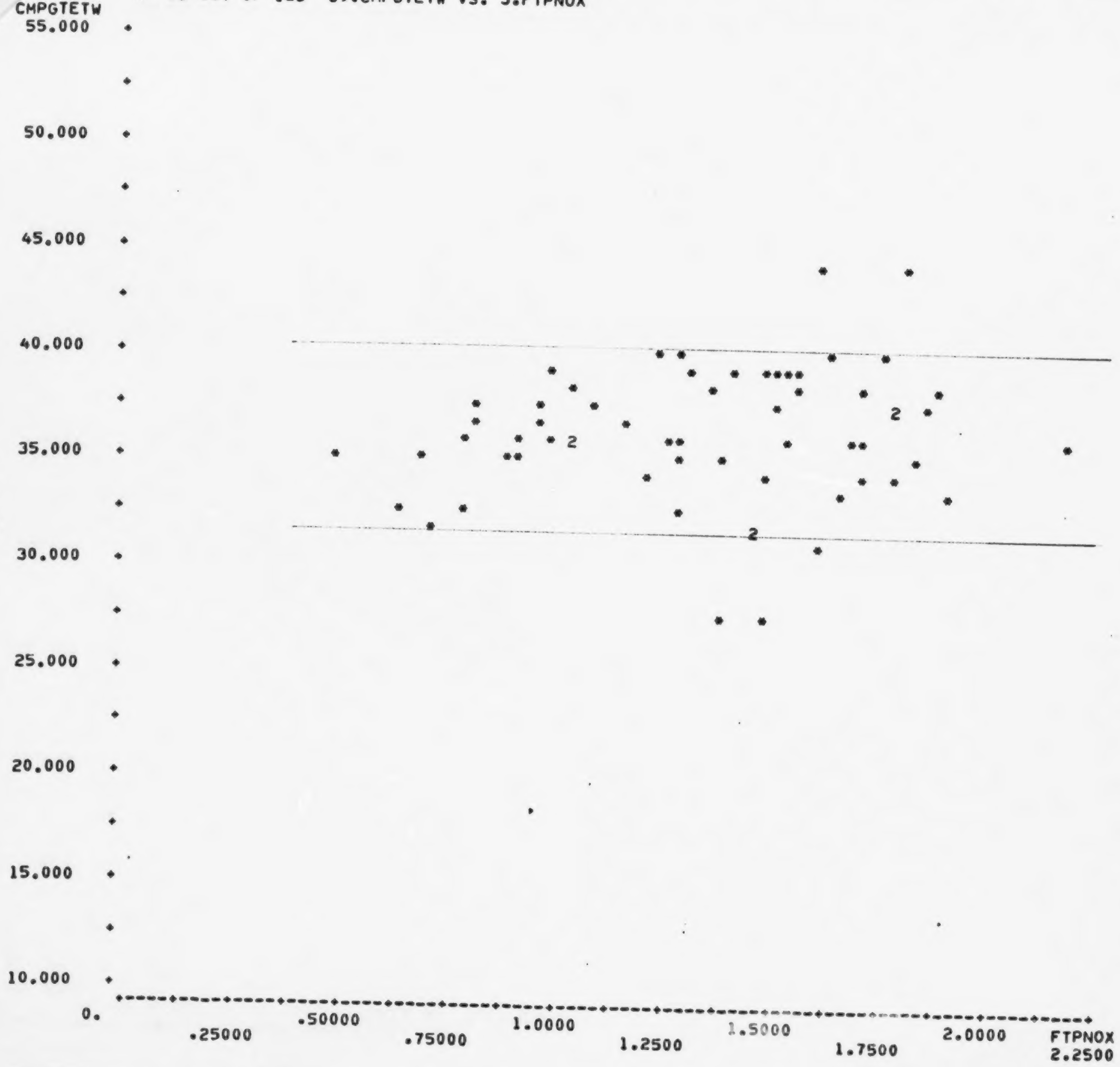


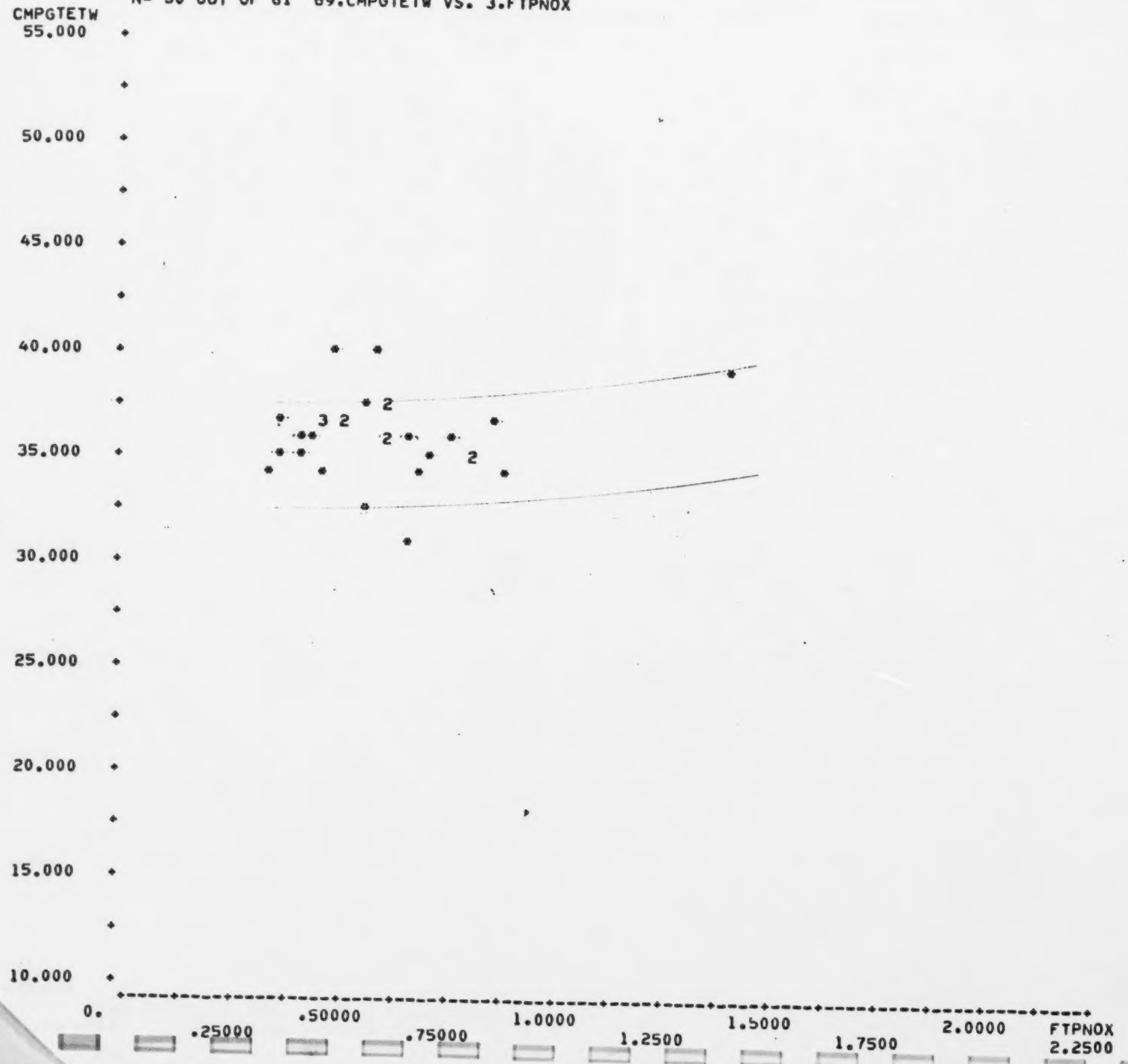
```
<SCATTER  BYST VAR=69!3 STRAT=V102*V28!(1,6,8),(2,3,4),(7,9) INTERVAL=(10.,55.)!(0.,2.25)>
SCATTER PLOT  <1> SYS1TO8!1*VTRN:(CA,CA,CA)
          N= 34 OUT OF 63  69.CMPGTETW VS. 3.FTPNOX
```



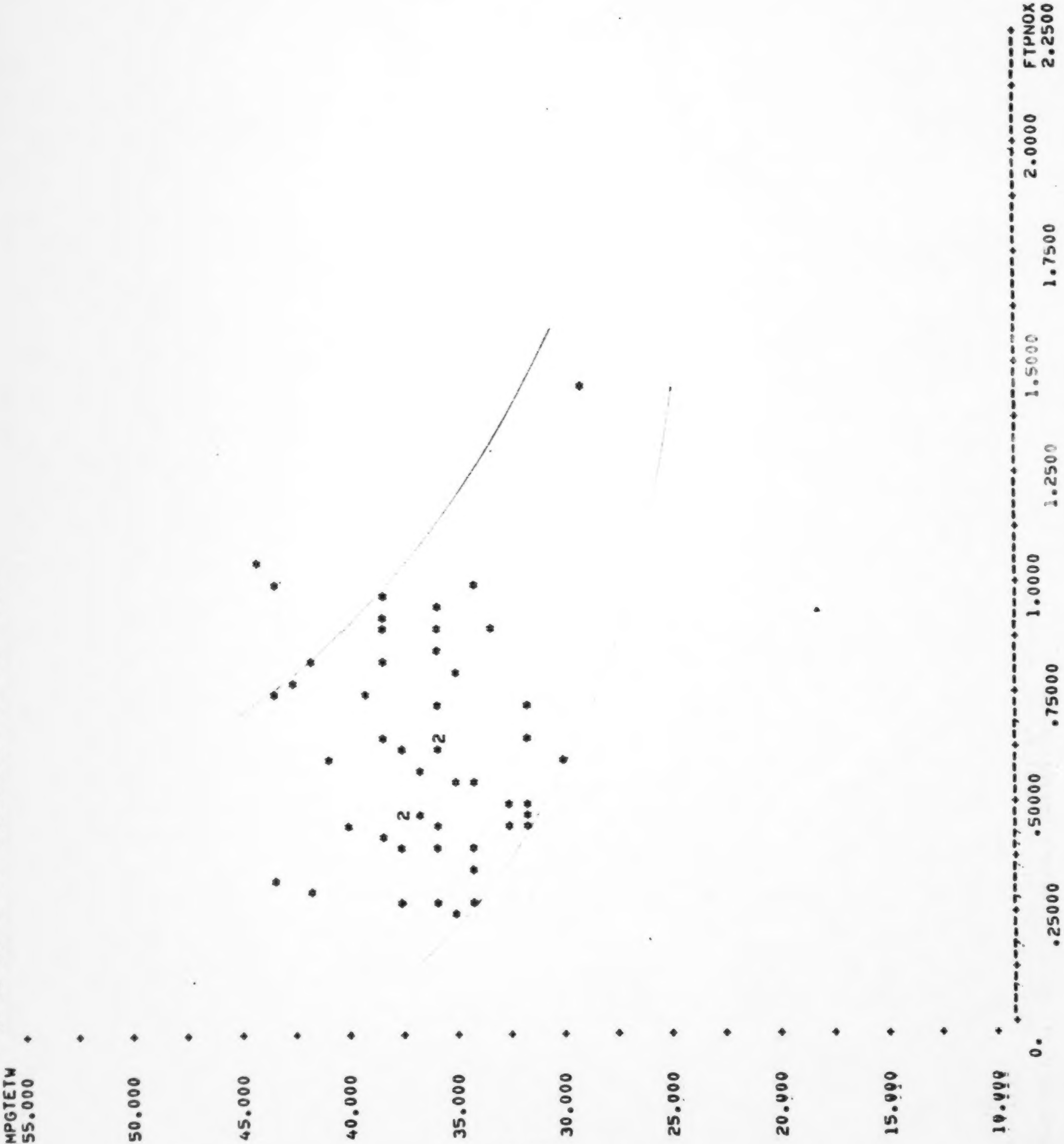
TTER PLOT <3> SYS1T08:3*VTRN:(CA,CA,CA)
N= 61 OUT OF 125 69.CMPGTETW VS. 3.FTPNOX



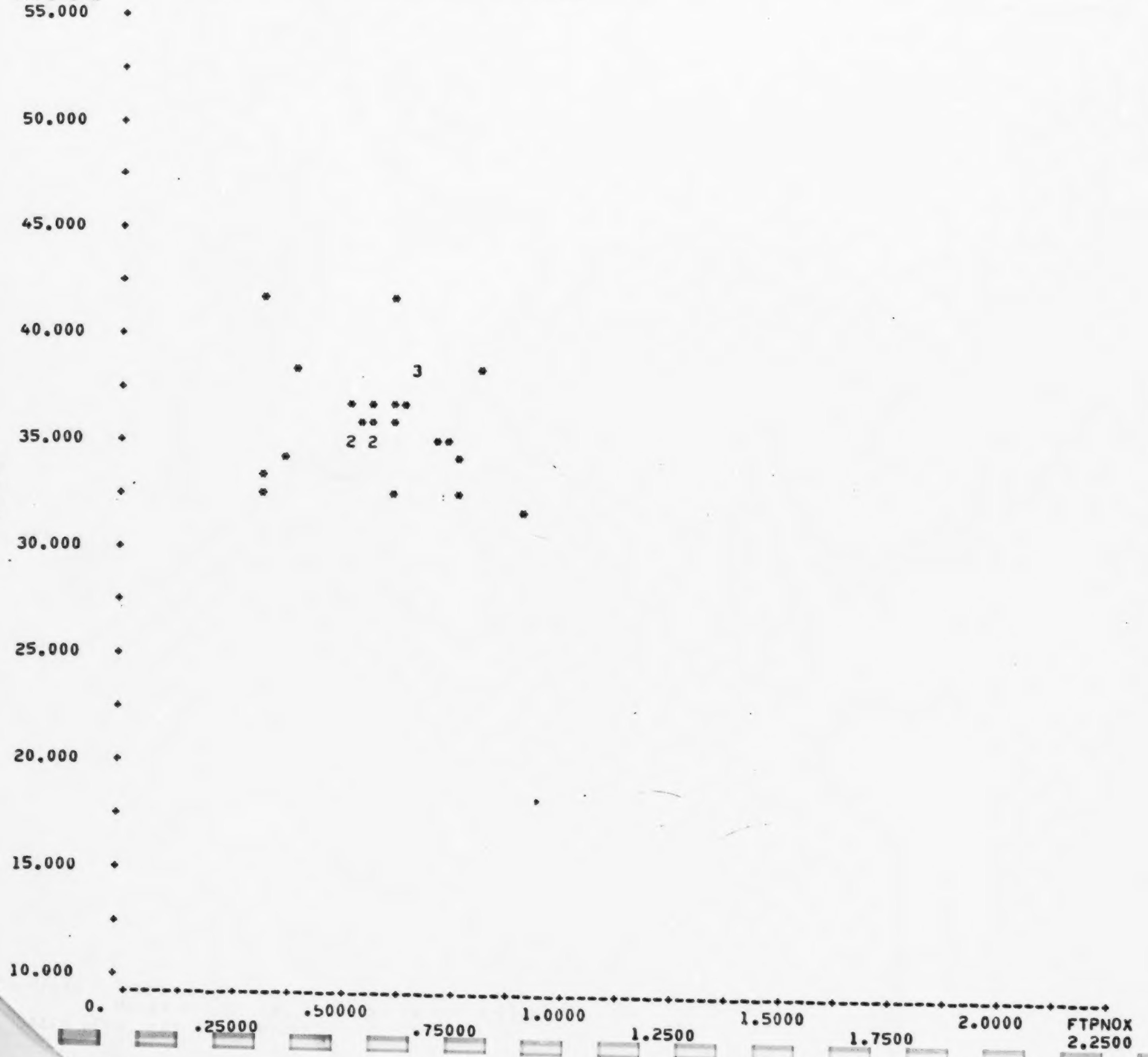
```
SCATTER PLOT  <4> SYS1T08:4*VTRN:(CA,CA,CA)
        N= 30 OUT OF 61  69.CMPGTETW VS. 3.FTPNOX
```



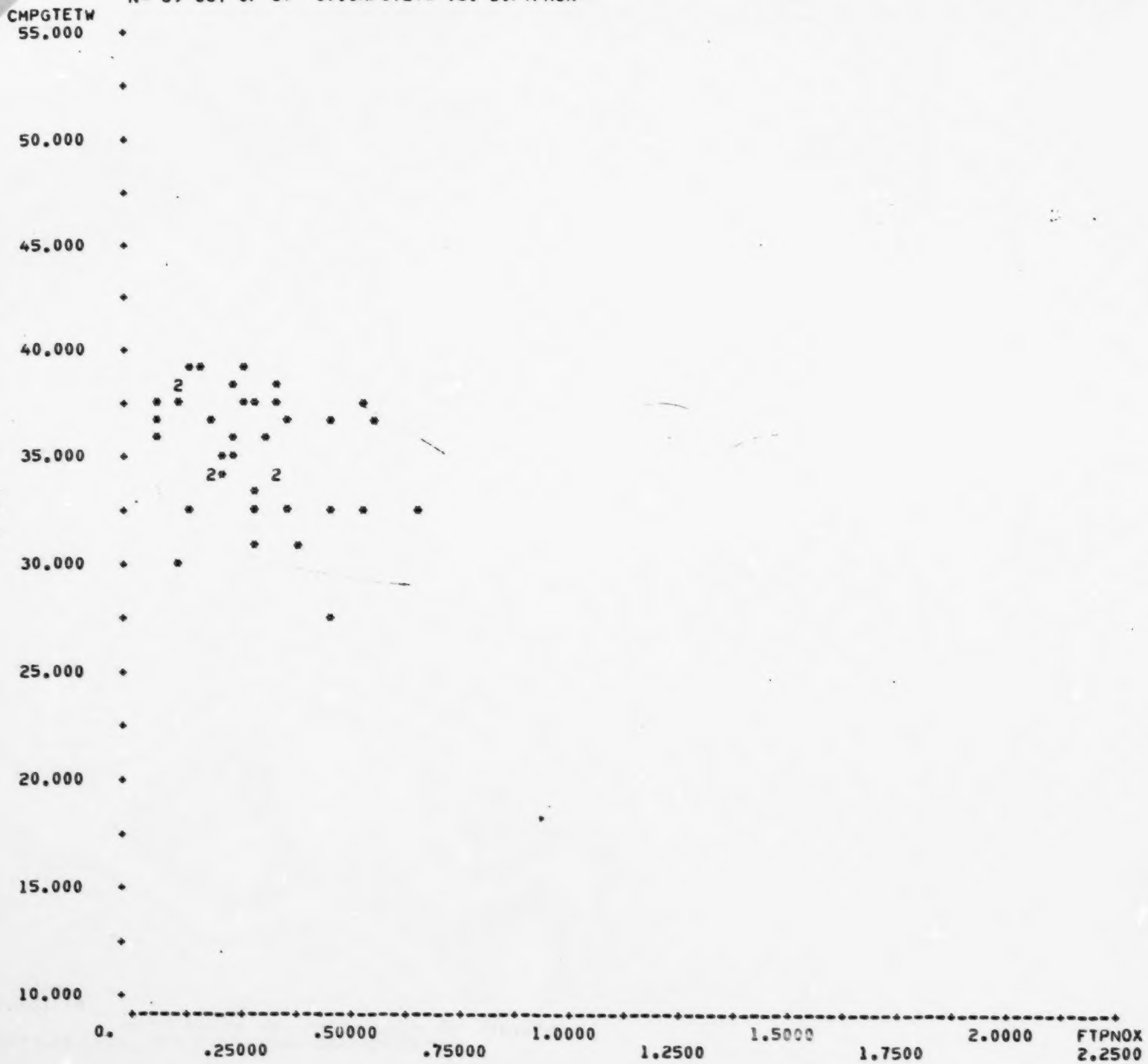
TTER PLOT <5> SYS1TOB:5 VTHN:(CA,CA,CA)
N= 51 OUT OF 79 69.CMPGTETW VS. 3.FTPNOX



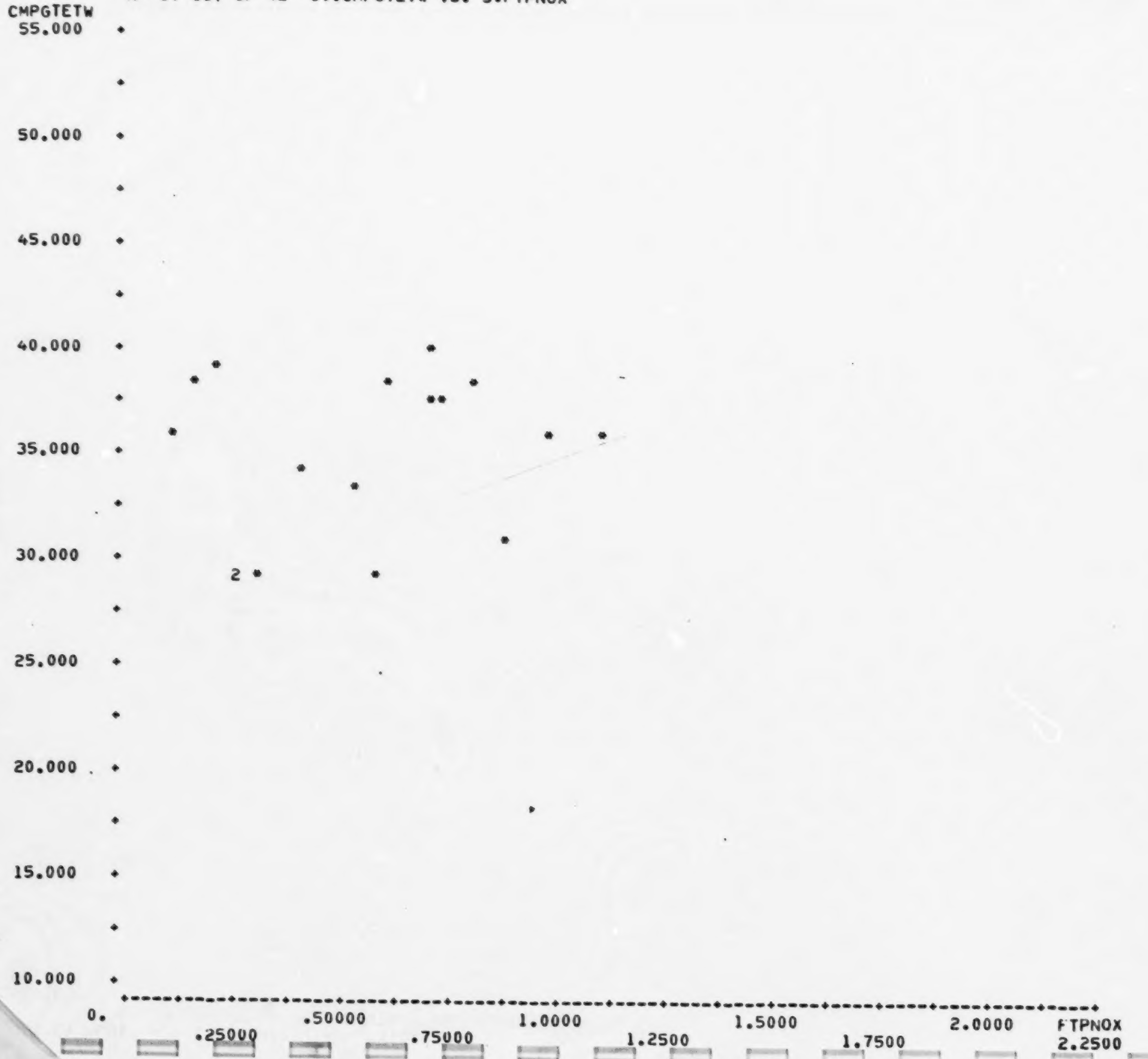
```
SCATTER PLOT  <6> SYS1T08:6*VTRN:(CA,CA,CA)
          N= 27 OUT OF 41  69.CMPGTETW VS. 3.FTPNOX
```



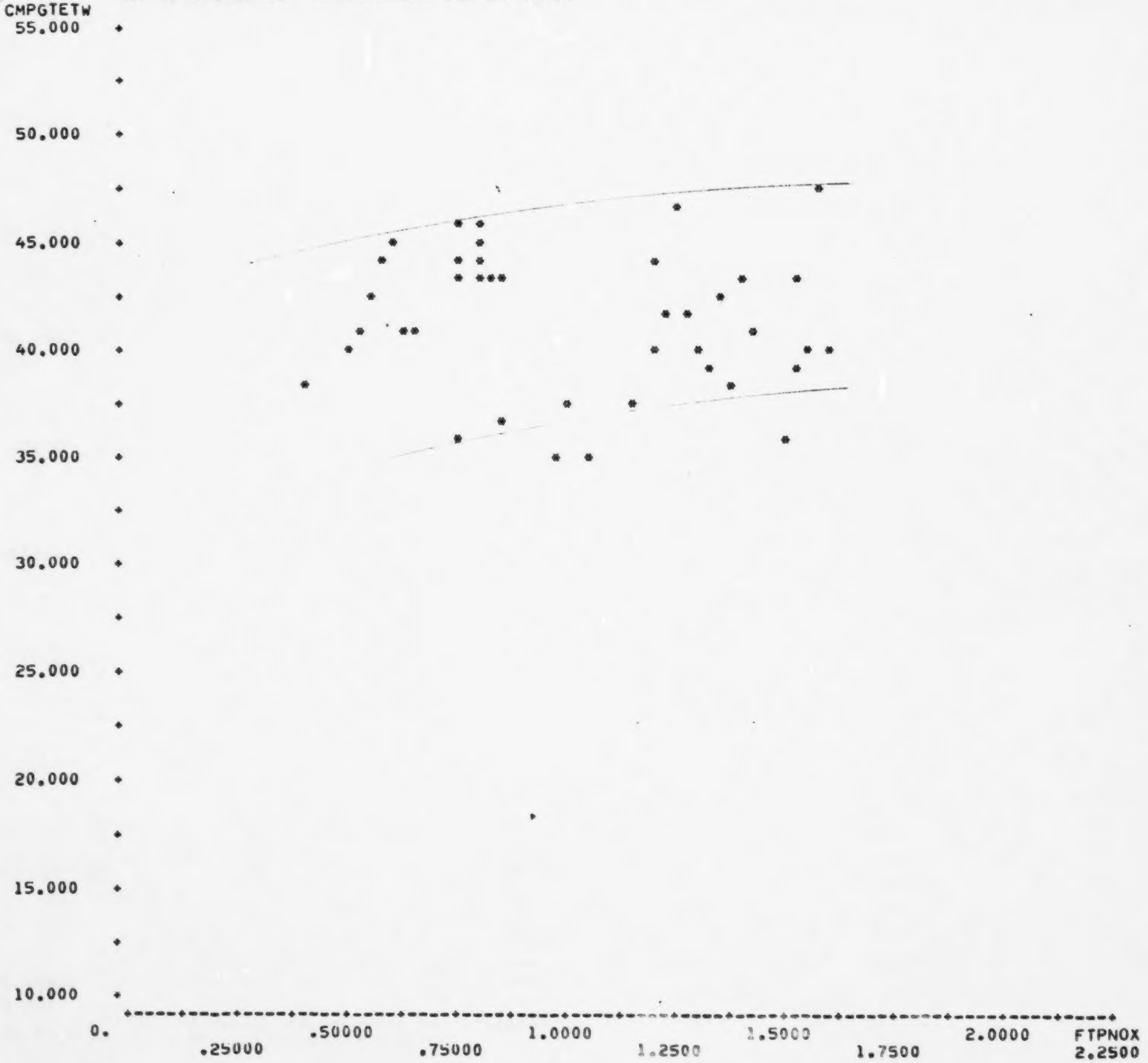
```
TTER PLOT  <7> SYSITO8:7*VTRN:(CA,CA,CA)
        N= 39 OUT OF 89  69.CMPGTETW VS. 3.FTPNOX
```



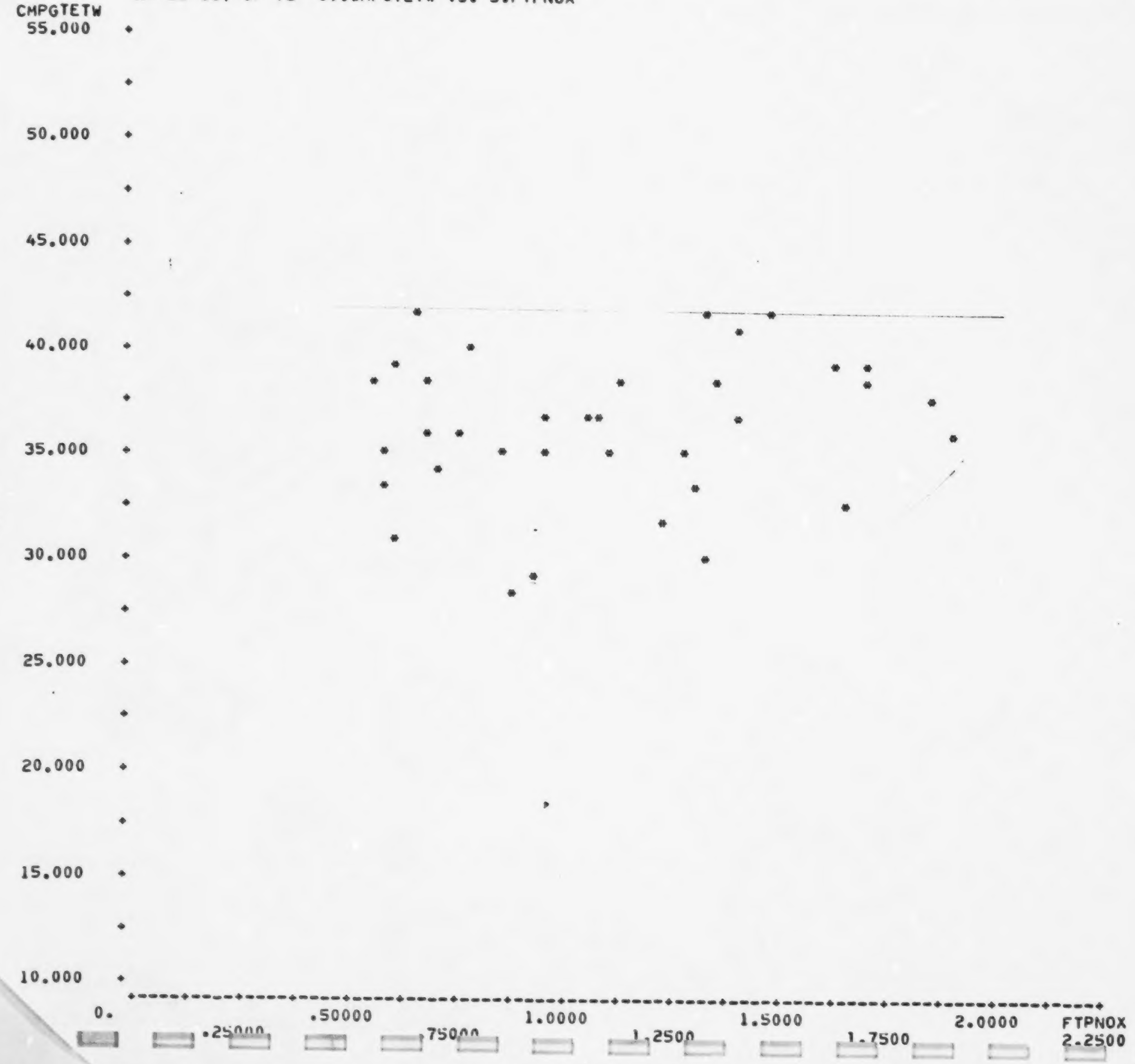
SCATTER PLOT <8> SYS1T08:8*VTRN:(CA,CA,CA)
N= 17 OUT OF 42 69.CMPGTETW VS. 3.FTPNOX



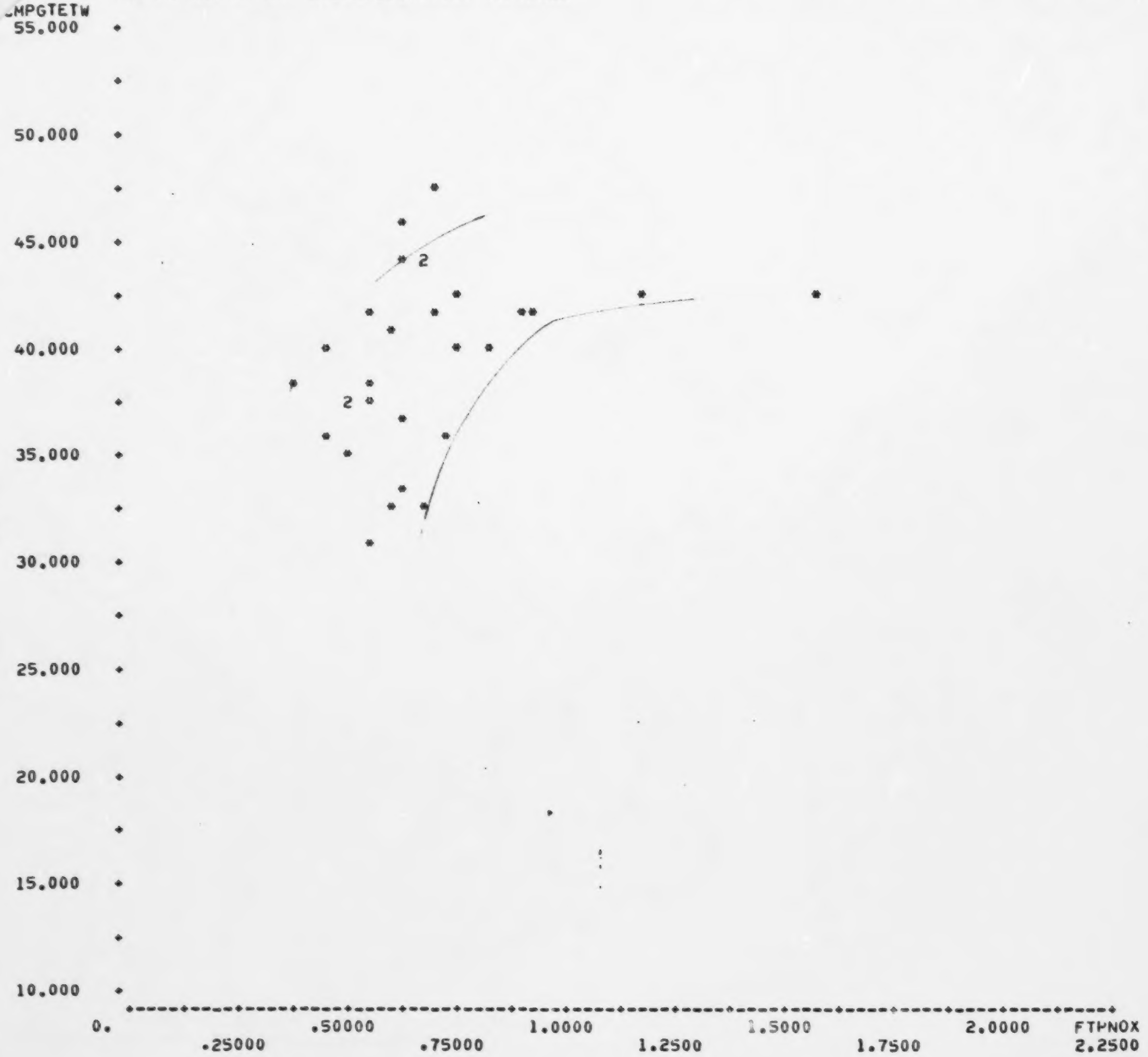
```
ATTER PLOT  <9> SYS1TO8:1*VTRN:(CM,CM,CM)
        N= 40 OUT OF 85  69.CMPGTETW VS. 3.FTPNOX
```



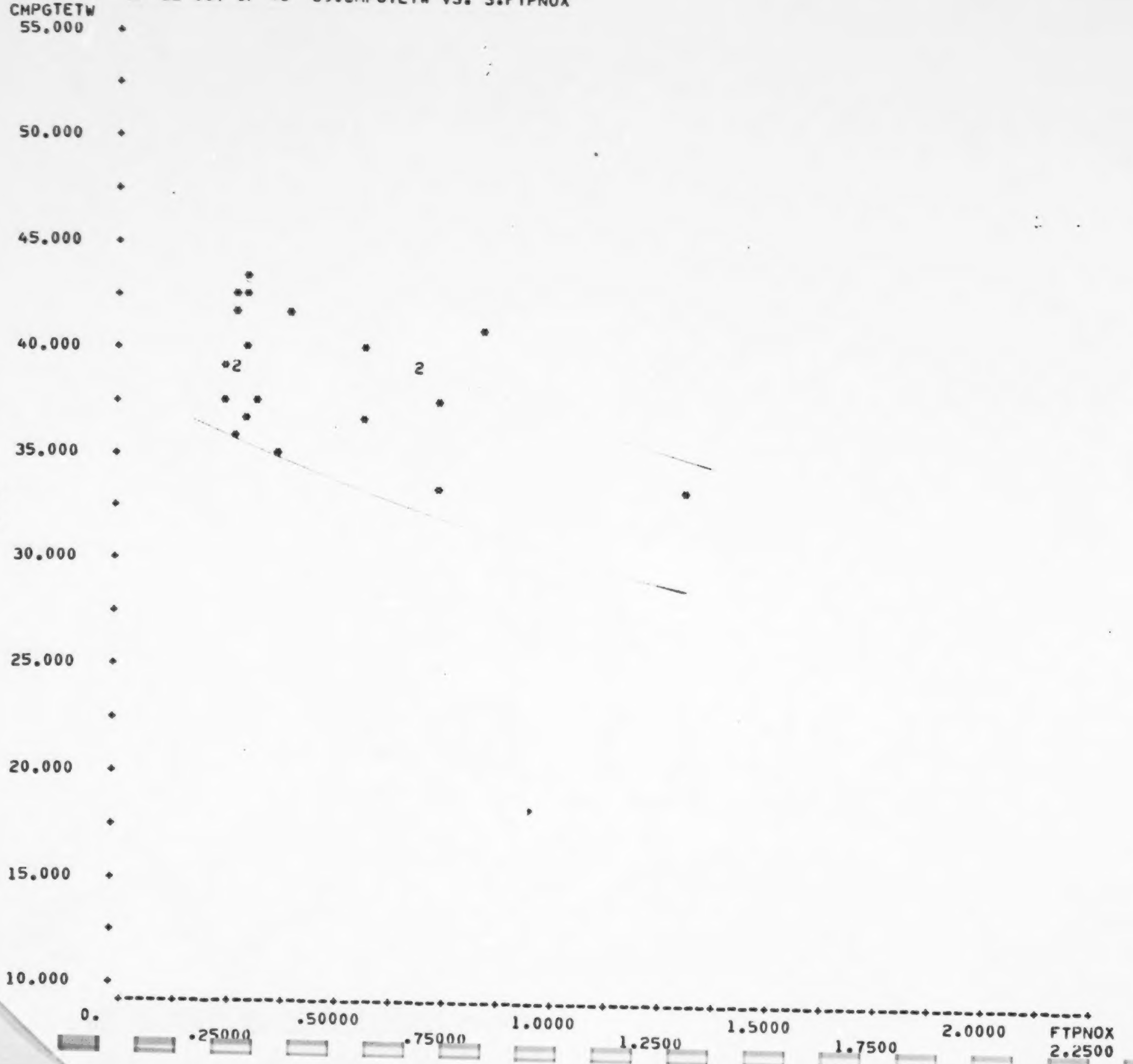
```
SCATTER PLOT  <11> SYS1TU8:3*VTRN:(CM,CM,CM)
        N= 35 OUT OF 72  69.CMPGTETW VS. 3.FTPNOX
```



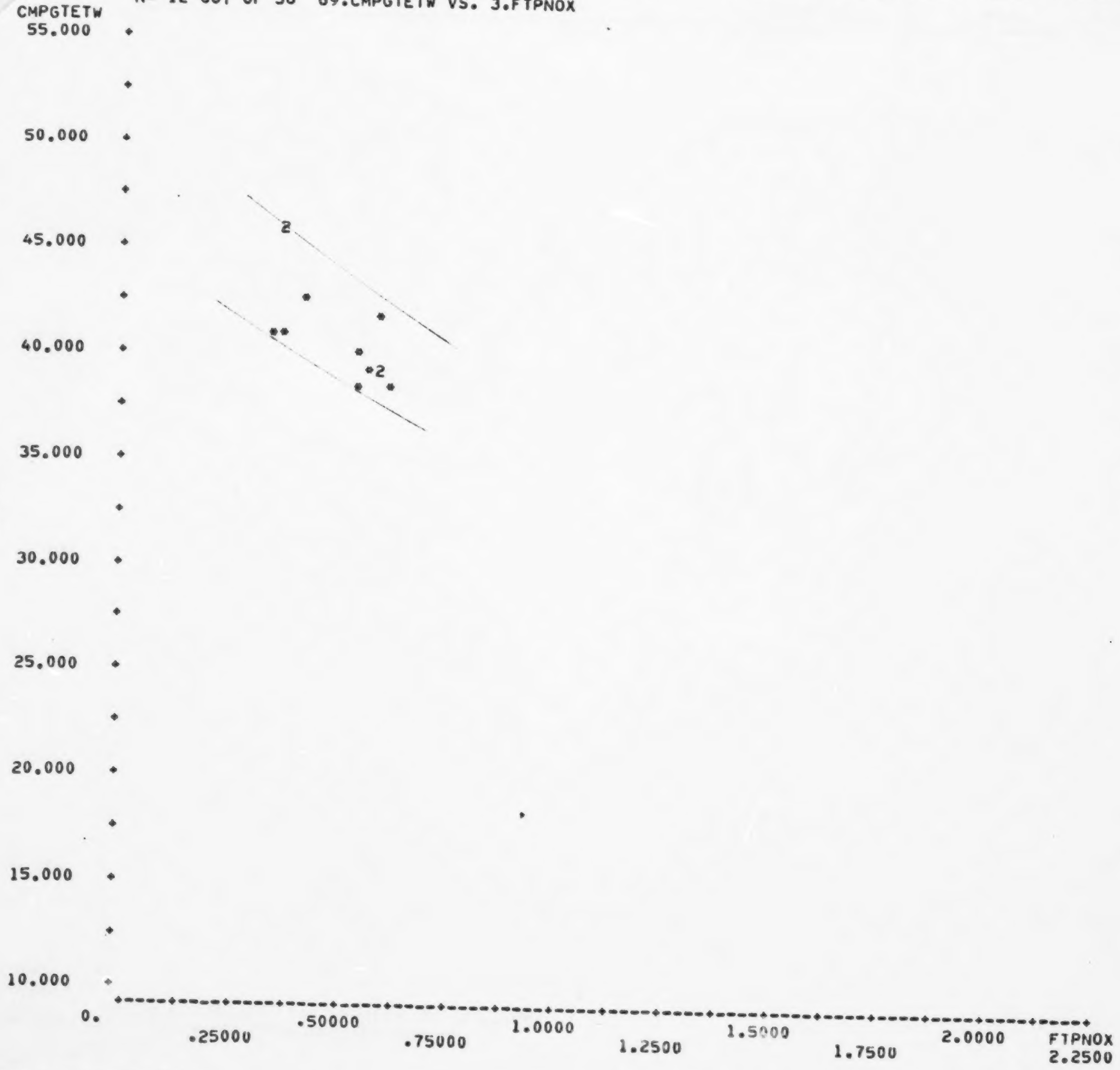
TER PLOT <12> SYS1TU8:4*VTRN:(CM,CM,CM)
N= 29 OUT OF 57 69.CMPGTETW VS. 3.FTPNOX



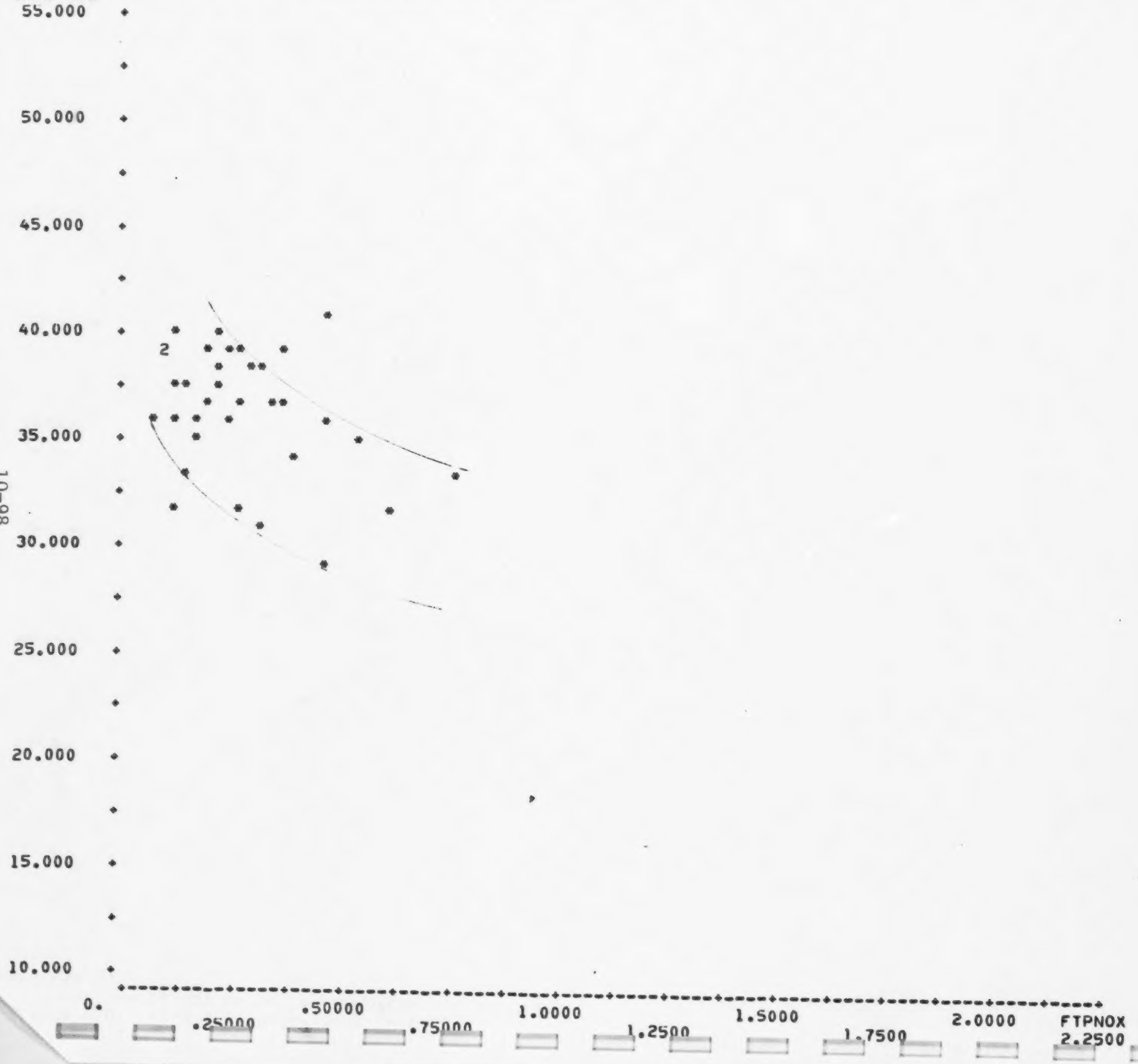
```
SCATTER PLOT  <13> SYS1T08:5*VTRN:(CM,CM,CM)
        N= 22 OUT OF 46  69.CMPGTETW VS. 3.FTPNOX
```



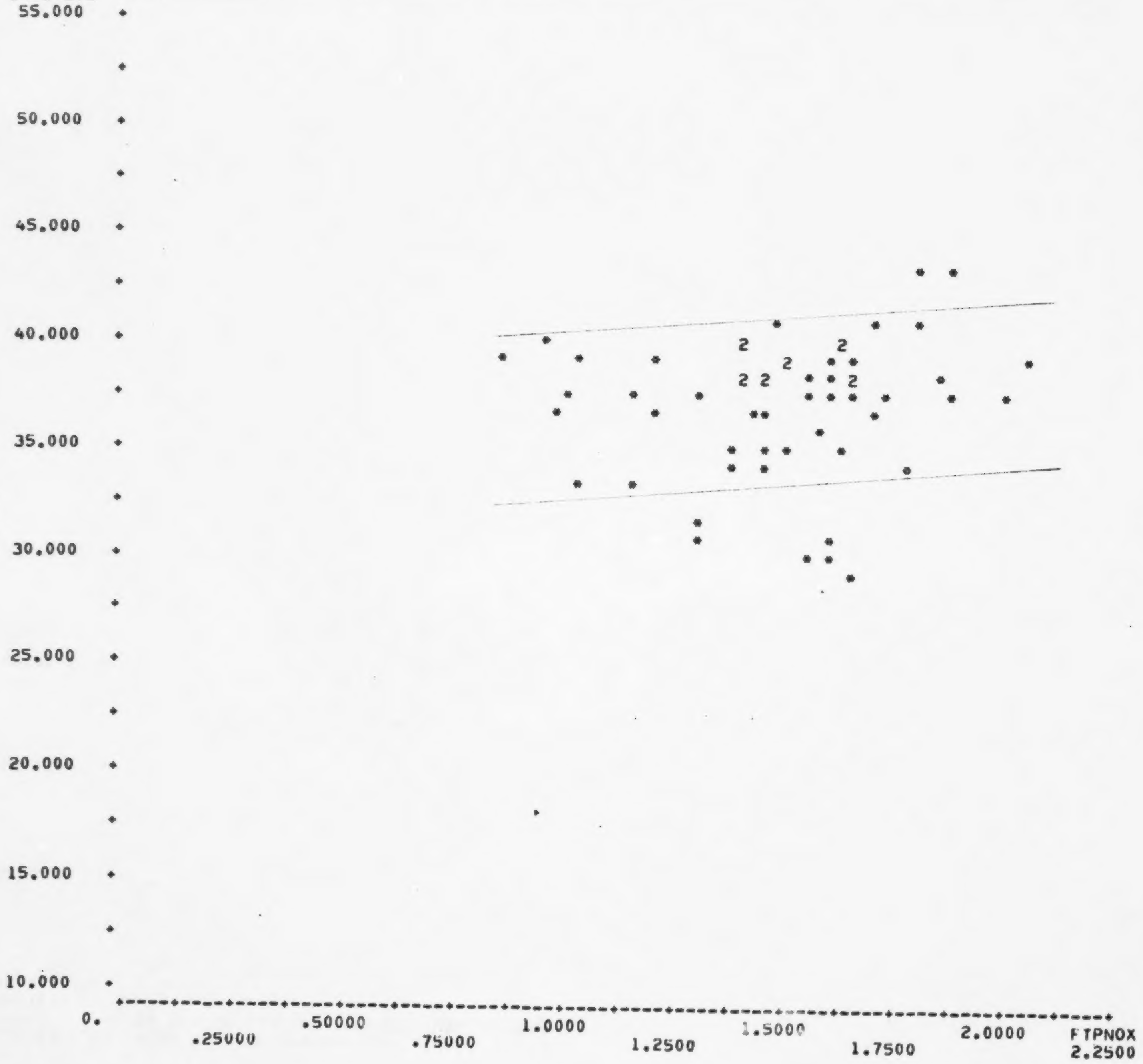
```
ATTER PLOT  <14> SYS1T08:6*VTRN:(CM,CM,CM)
        N= 12 OUT OF 36  69.CMPGTETW VS. 3.FTPNOX
```



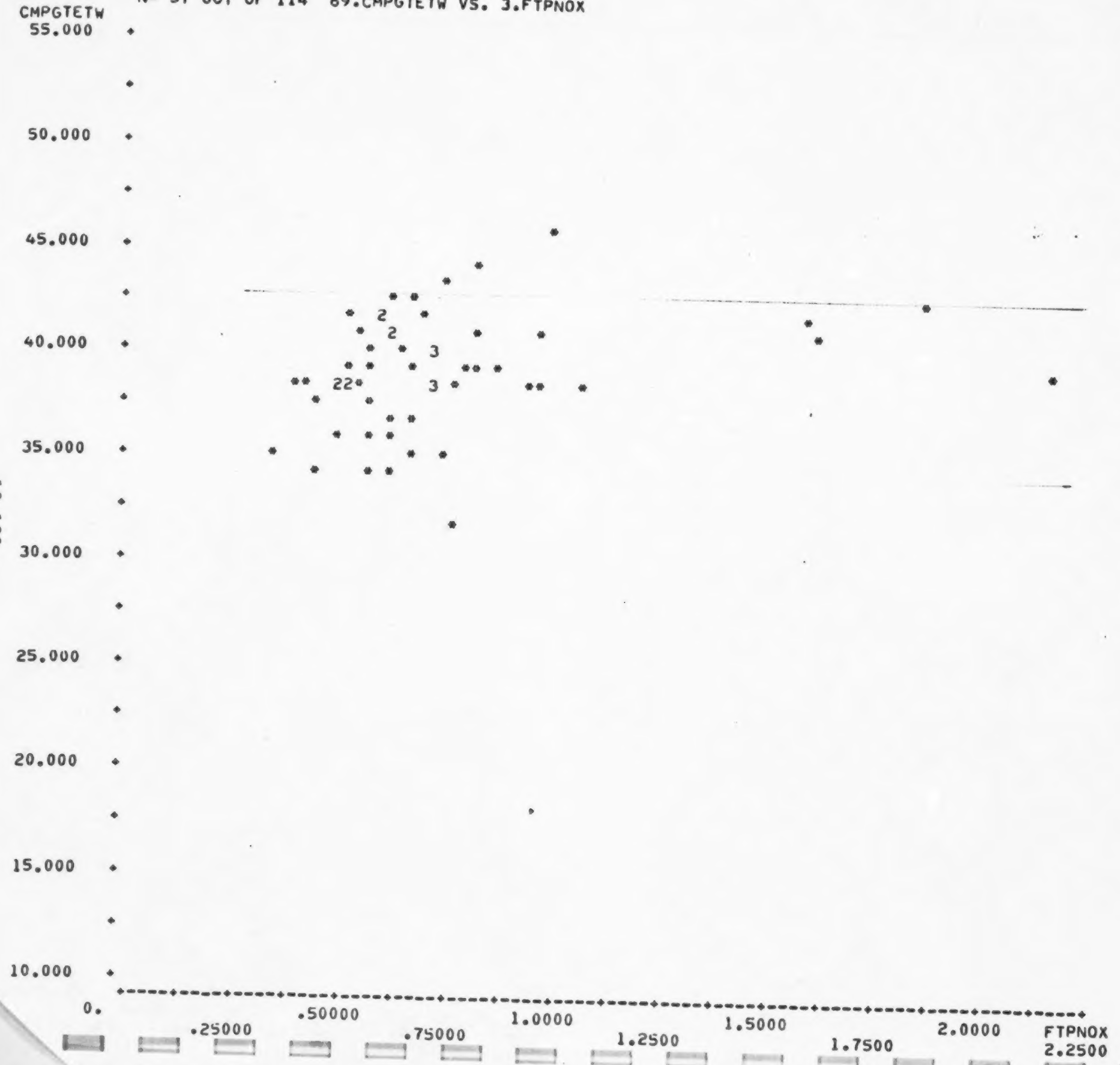
```
SCATTER PLOT  <15> SYS1T08:7*VTRN:(CM,CM,CM)
          N= 34 OUT OF 82  69.CMPGTETW VS. 3.FTPNOX
```



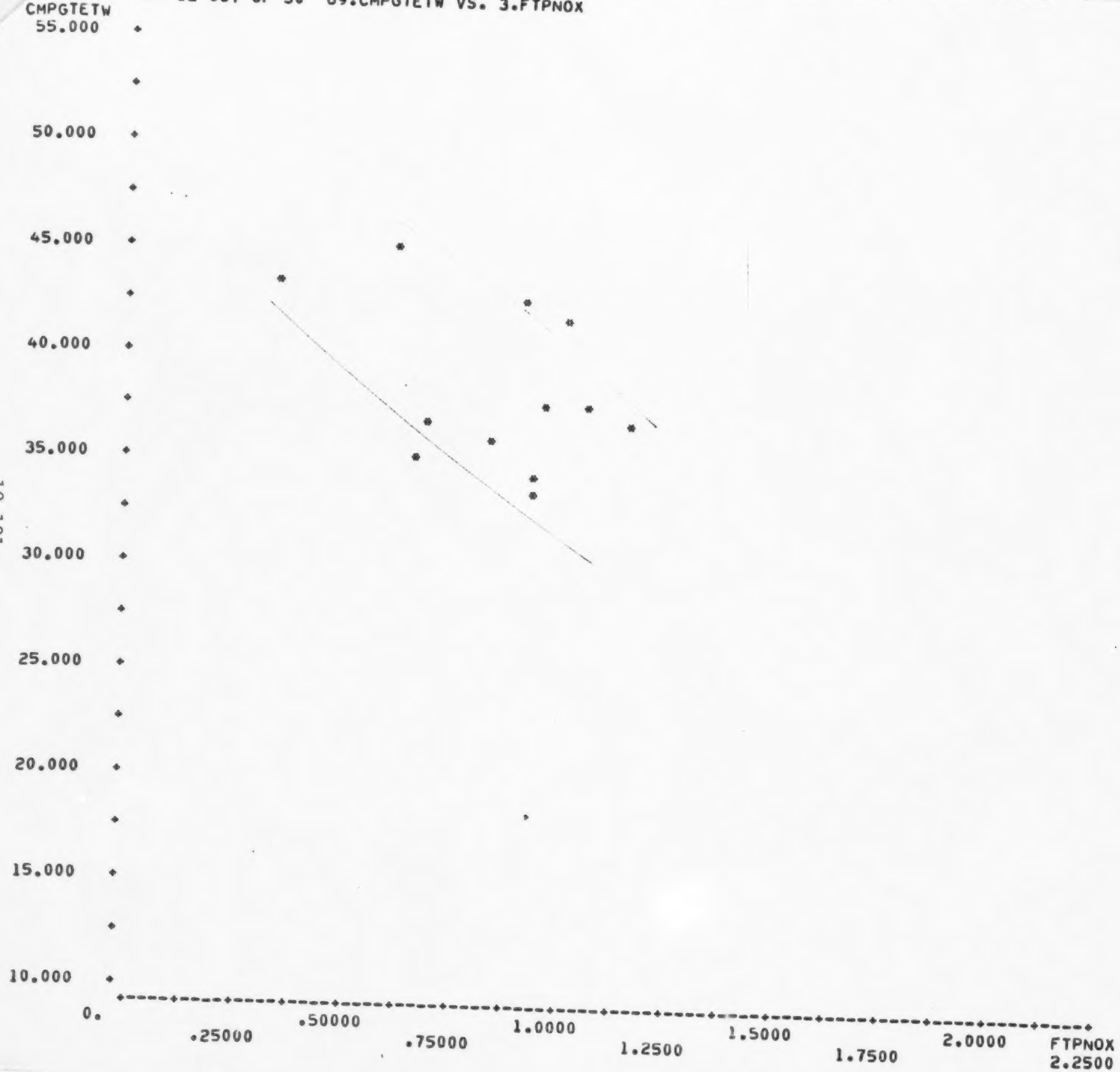
```
ATTER PLOT  <19> SYSIT08:3*VTRN:(LA.LA)
     N= 57 OUT OF 87  69.CMPGTETW VS. 3.FTPNOX
```



```
SCATTER PLOT  <20> SYS1T08:4*VTRN!(LA.LA)
        N= 57 OUT OF 114  69.CMPGTETW VS. 3.FTPNOX
```



```
ATTER PLOT  <21> SYS1TO8:5*VTRN:(LA,LA)
        N= 12 OUT OF 30  69.CMPGTETW VS. 3.FTPNOX
```



Appendix 11

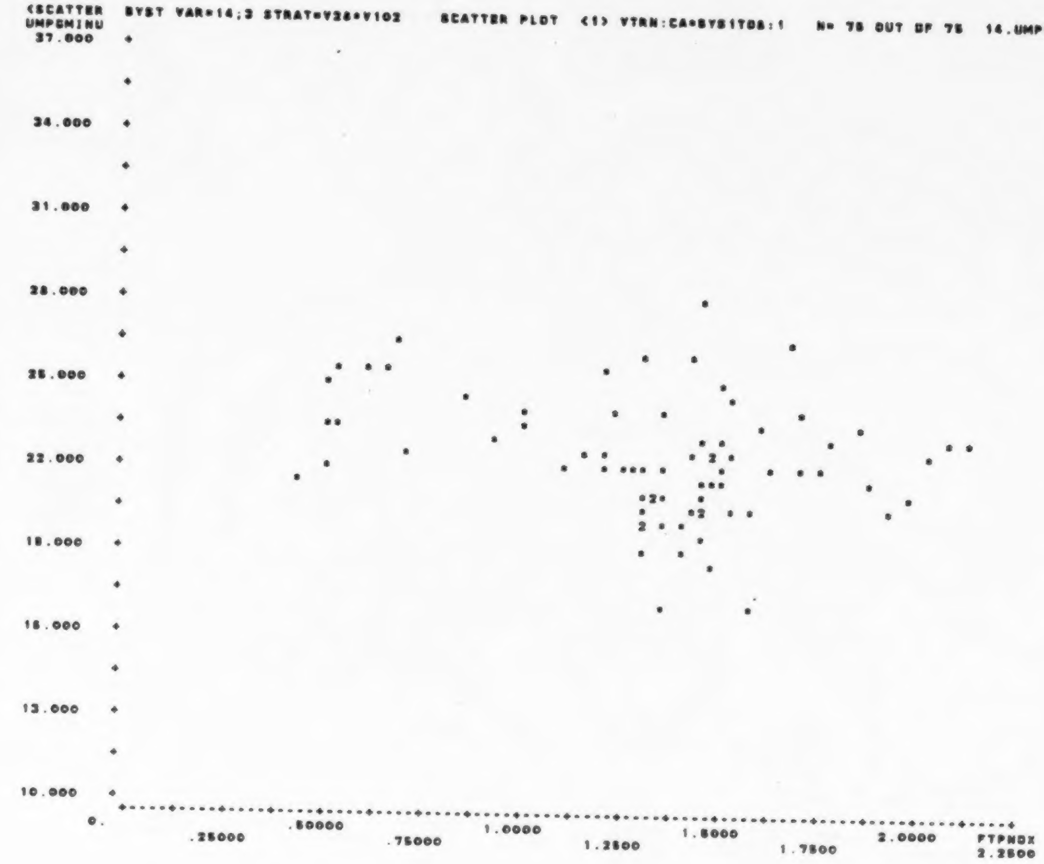
Adjusted Fuel Economy versus Emissions by Emission Control System and Transmission Type

Two variable linear regression plots of "Adjusted Urban Fuel Economy" (UMPGMINU) and "Adjusted Combined Fuel Economy" (CMPGMINU), each plotted against FTPNOX.

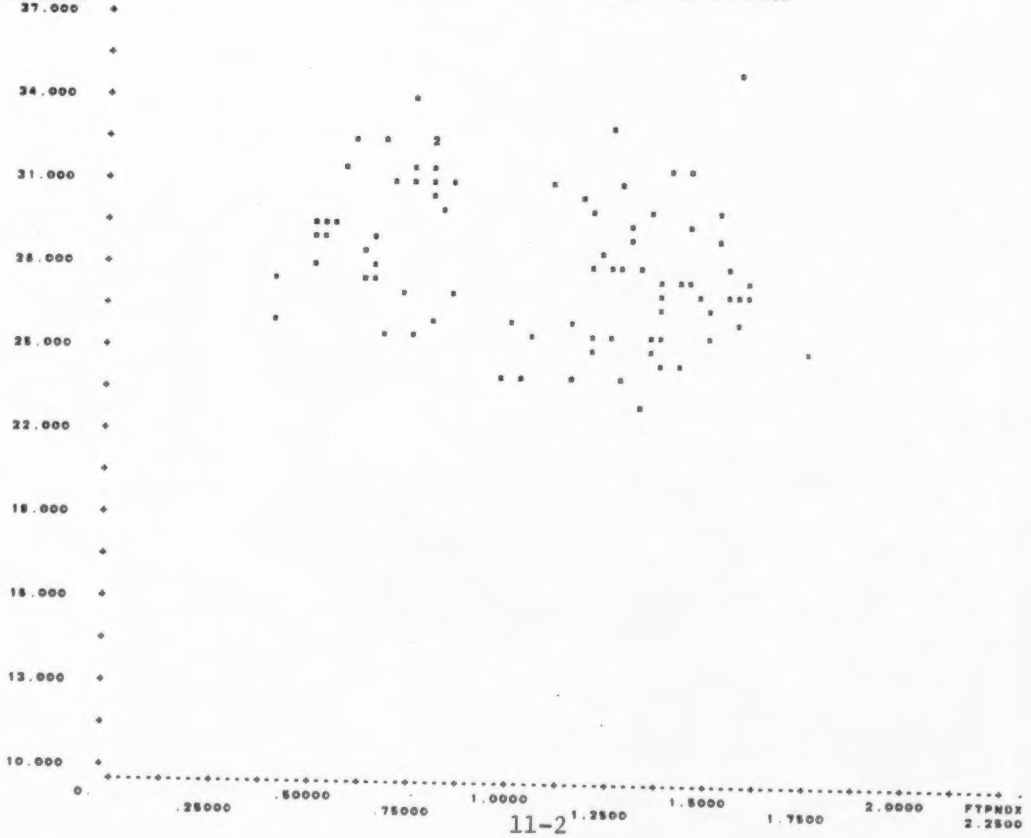
Data from EPA/CERT Data Base, restricted to non-durability, non-Diesel vehicles of test active year 1979 to 1981 was used.

Stratification by emission control system and by transmission type (CA, CM, and LA). (See Section IV. H.)

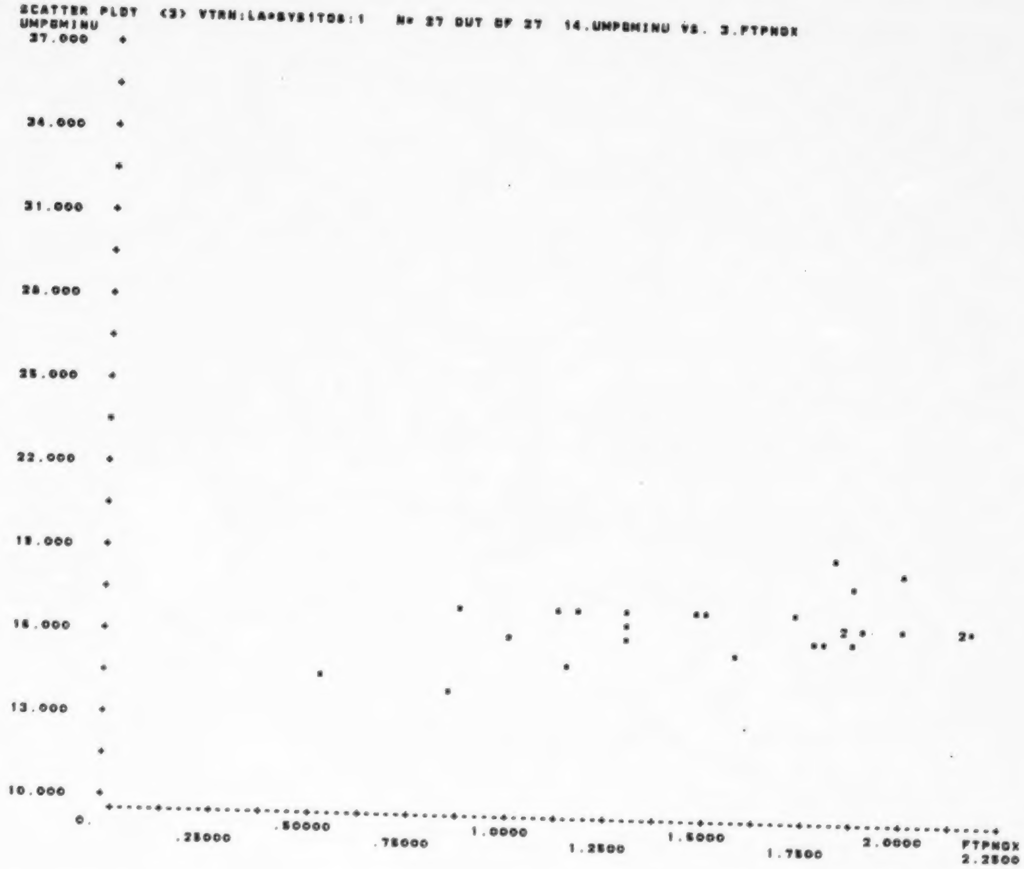
```
<SCATTER  BYST VAR=14;3 STRAT=V26*V102    SCATTER PLOT  <1> VTRN:CA*SYS1TD8:1   N= 75 OUT OF 75  14.UMPGMINU VS. 3.FTPNOX
```



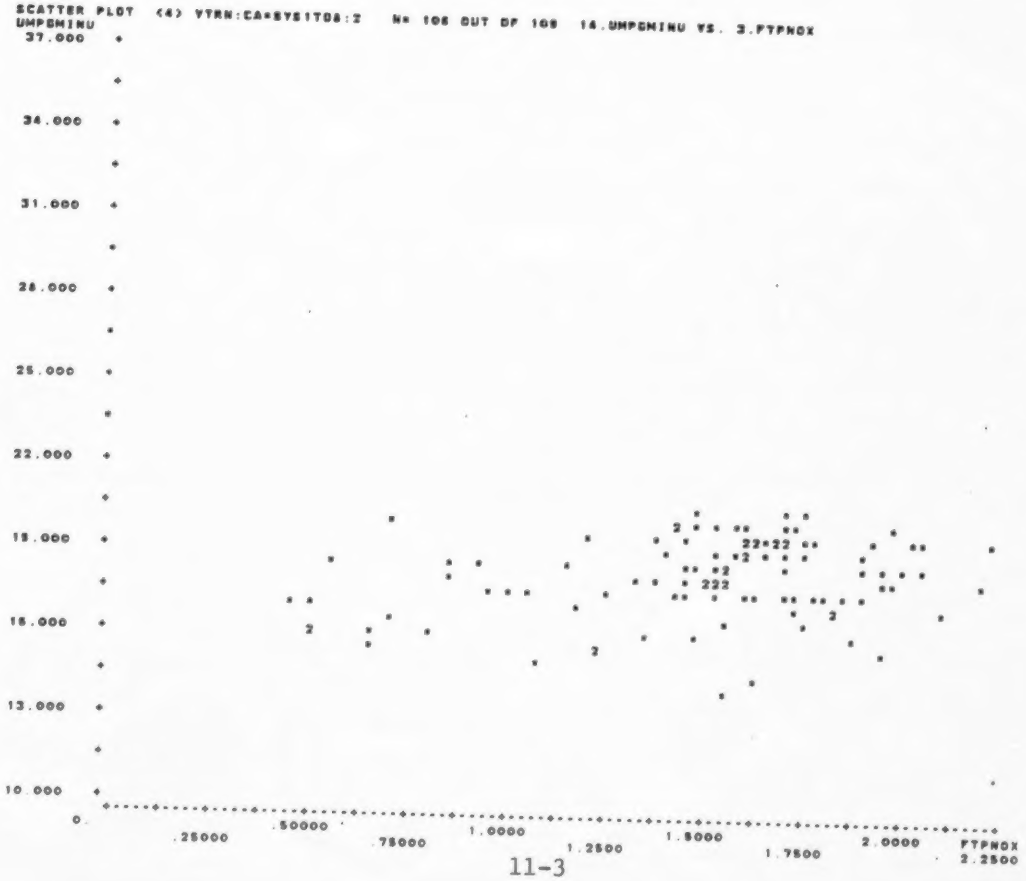
```
SCATTER PLOT  <2> VTRN:CM*SYS1TD8:1   N= 82 OUT OF 84  14.UMPGMINU VS. 3.FTPNOX
```



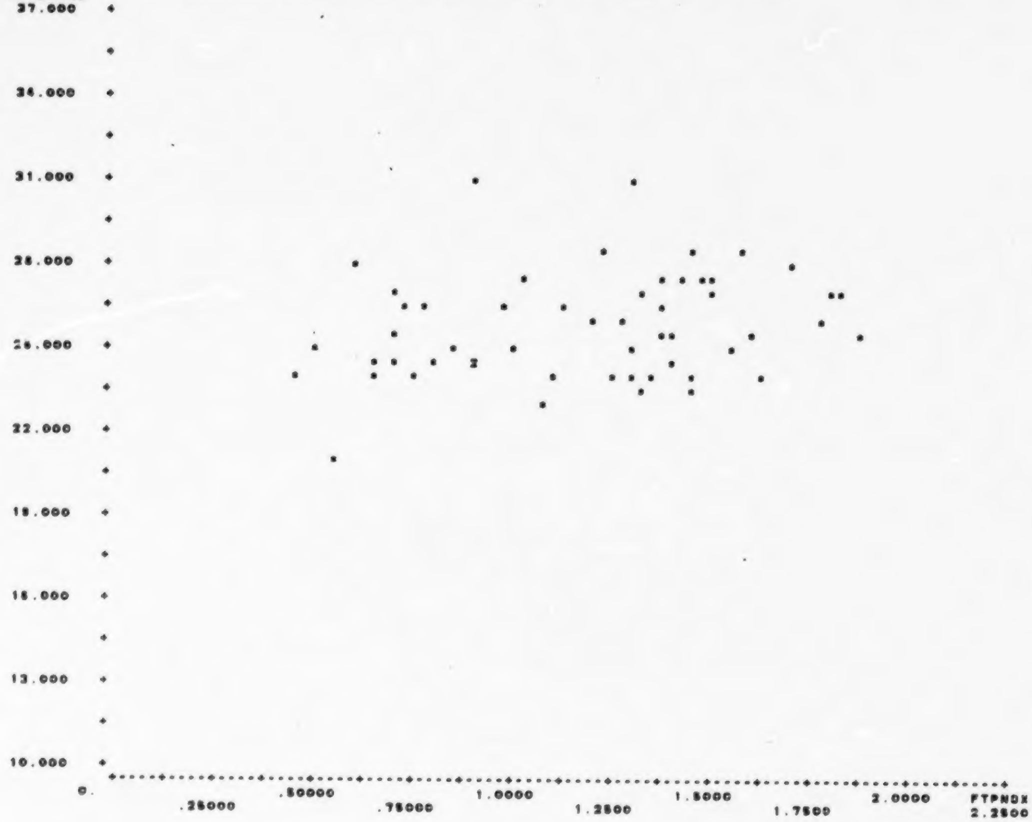
SCATTER PLOT (3) VTRN:LA*SYS1T08:1 N= 27 OUT OF 27 14.UMPGMINU VS. 3.FTPNOX



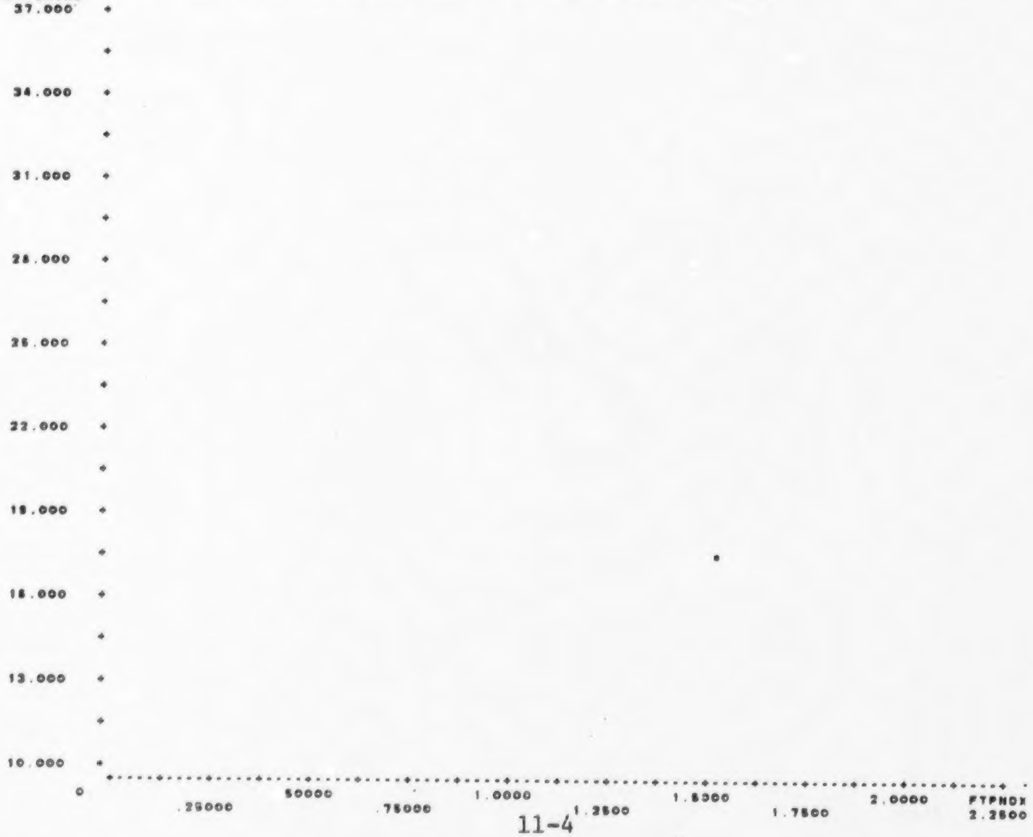
SCATTER PLOT (4) VTRN:CA*SYS1T08:2 N= 106 OUT OF 109 14.UMPGMINU VS. 3.FTPNOX



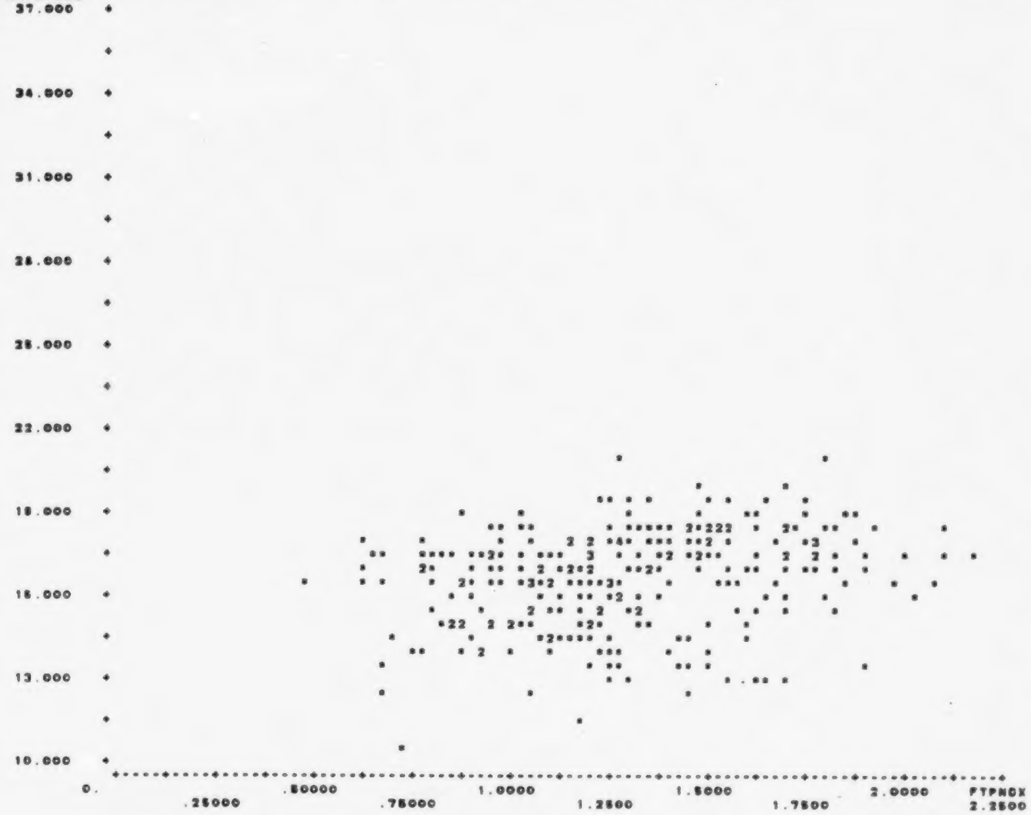
SCATTER PLOT (5) VTRN:CM*SYS1TDS:2 N= 54 OUT OF 54 14.UMPGMINU VS. 3.FTPNOX



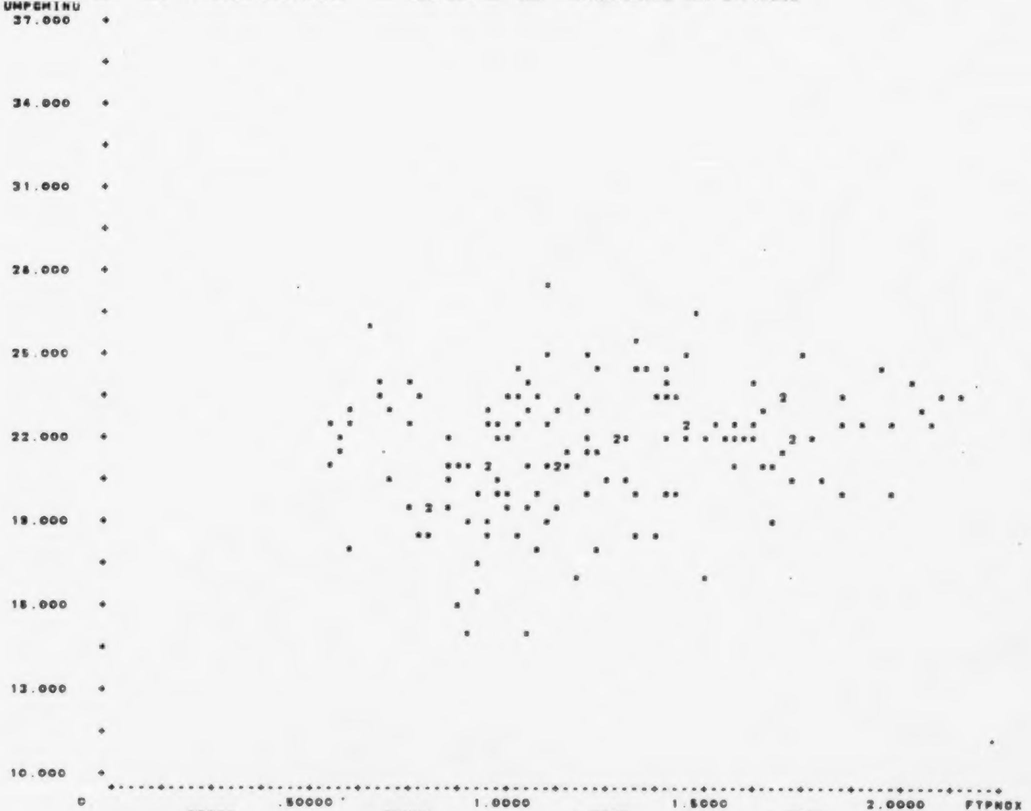
SCATTER PLOT (6) VTRN:LA*SYS1TDS:2 N= 1 OUT OF 1 14.UMPGMINU VS. 3.FTPNOX



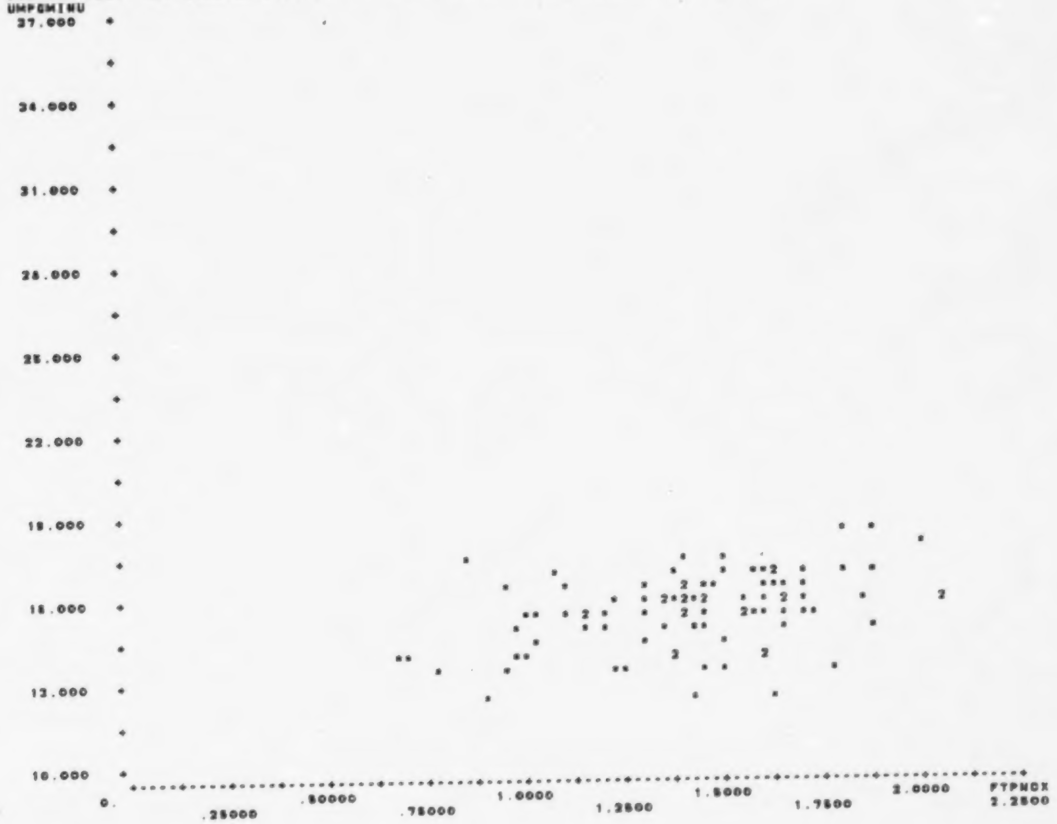
SCATTER PLOT (7) VTRN:CA*SYS1TDS:3 N= 270 OUT OF 271 14.UMPGMINU VS. 3.FTPNOX



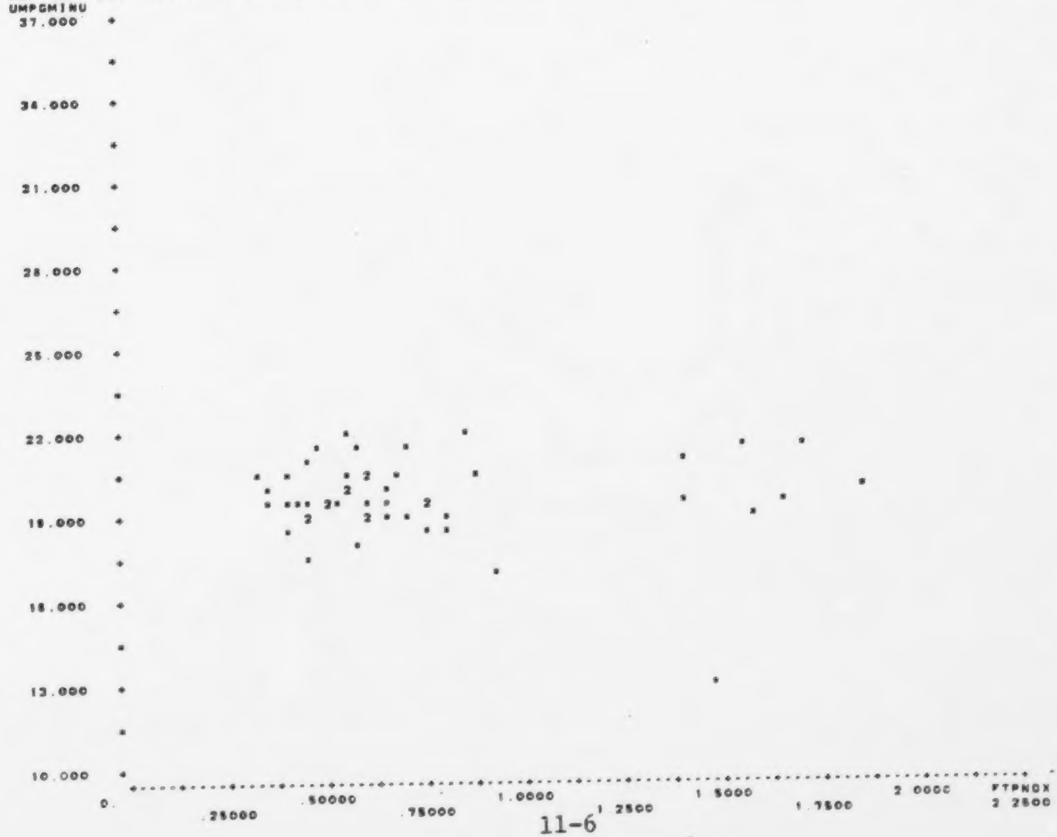
SCATTER PLOT (8) VTRN:CM*SYS1TDS:3 N= 139 OUT OF 139 14.UMPGMINU VS. 3.FTPNOX

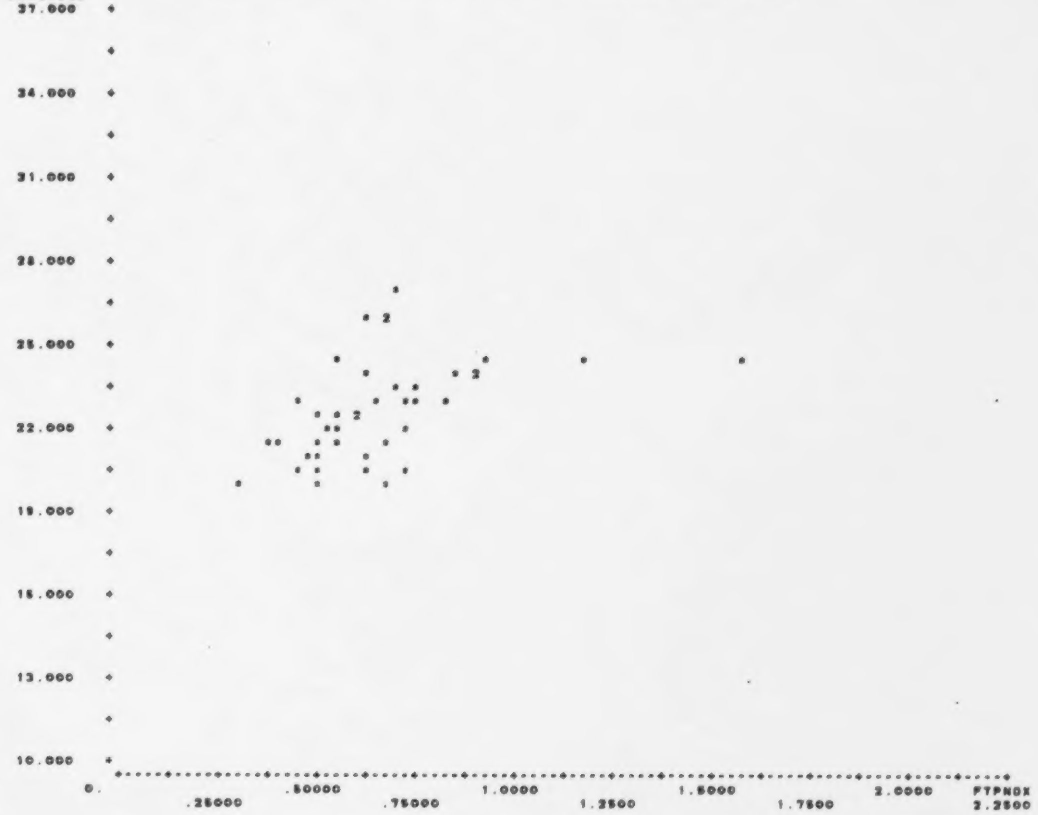


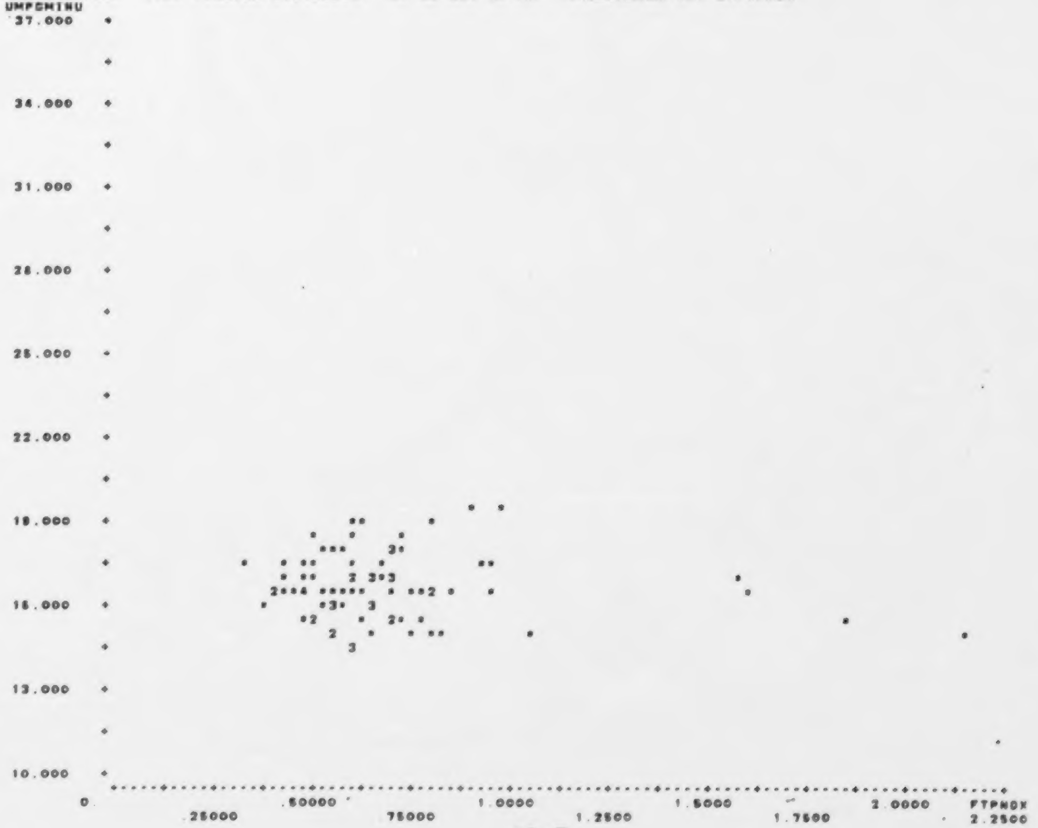
SCATTER PLOT (9) VTRN:LA*SYS1TD8:3 N= 51 OUT OF 51 14.UMPGMINU VS. 3.FTPNOX



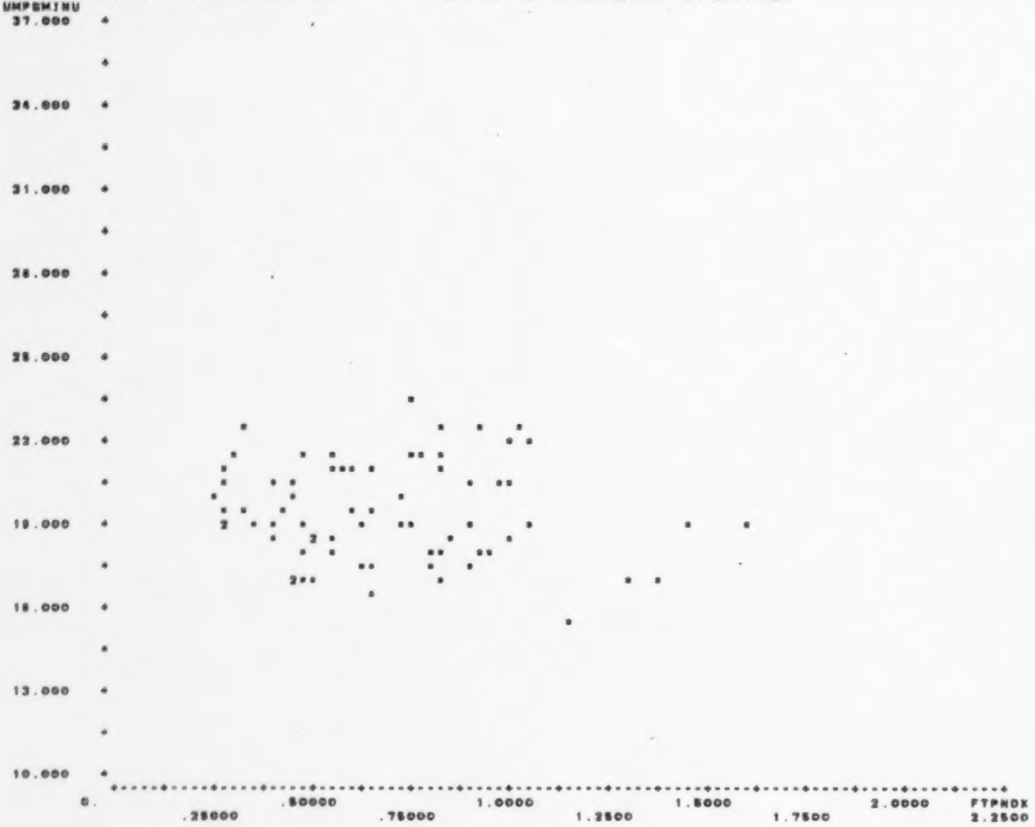
SCATTER PLOT (10) VTRN:CA*SYS1TD8:4 N= 49 OUT OF 49 14.UMPGMINU VS. 3.FTPNOX



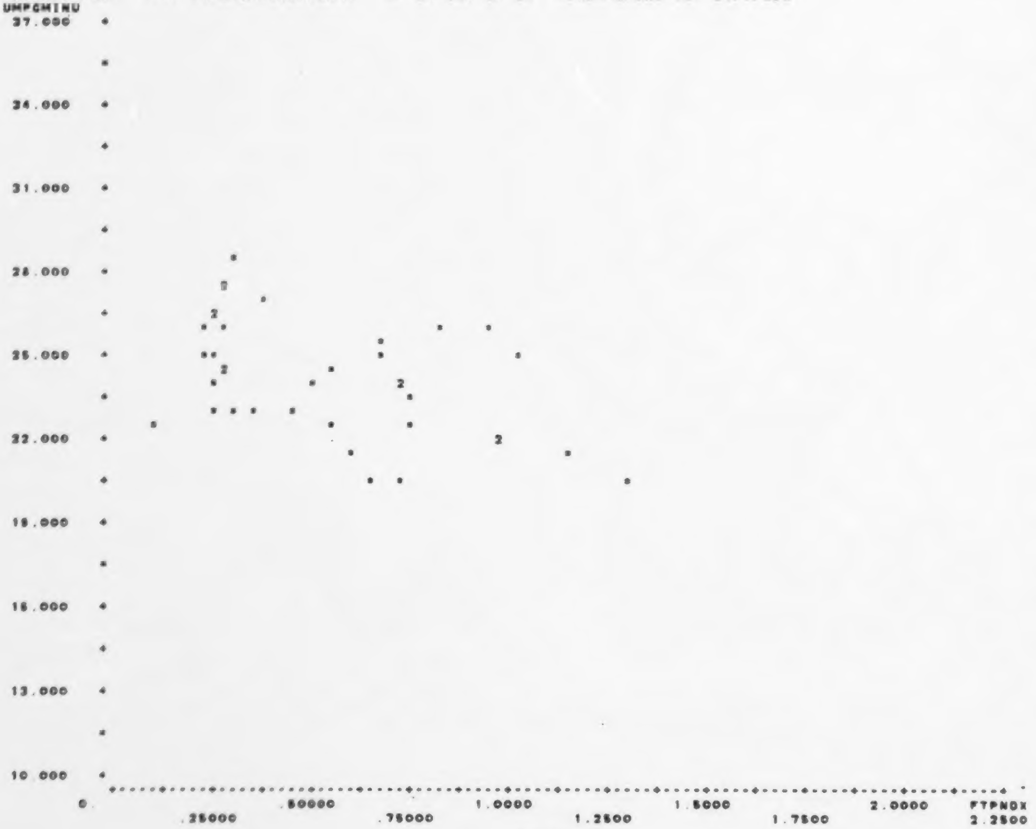

SCATTER PLOT (11) VTRN:CM*SYS1TD8:4 N= 41 OUT OF 41 14.UMPGMINU VS. 3.FTPNOX


SCATTER PLOT (12) VTRN:LA*SYS1TD8:4 N= 66 OUT OF 66 14.UMPGMINU VS. 3.FTPNOX

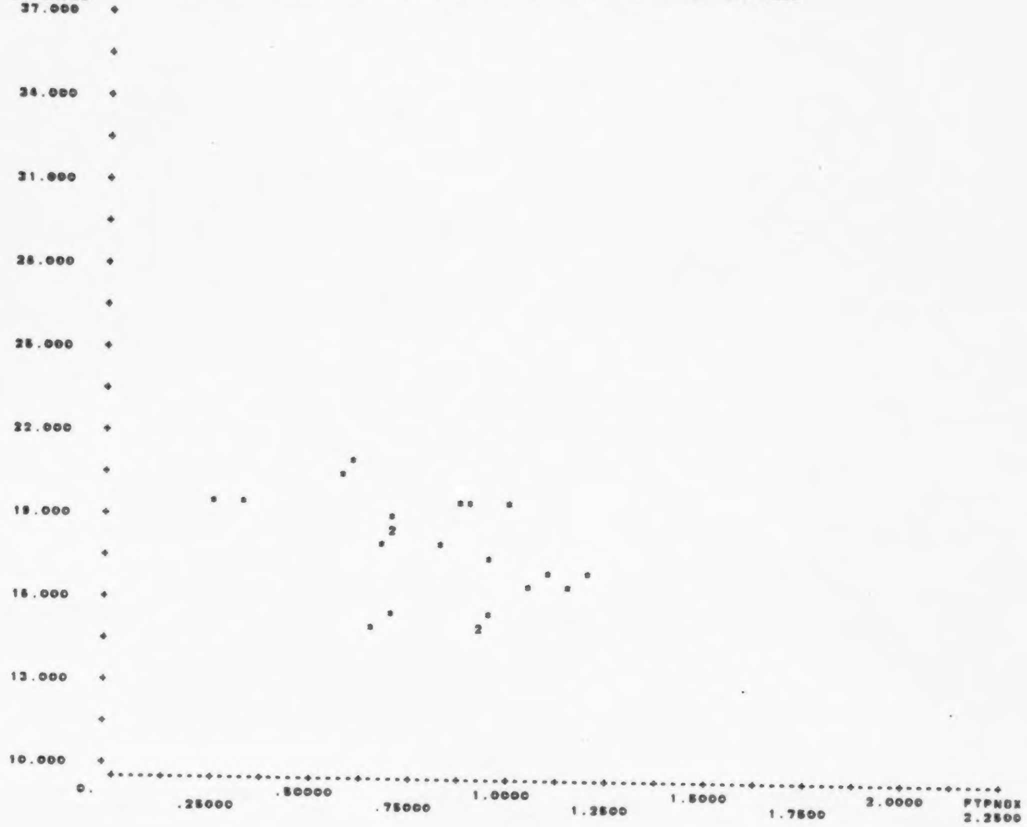
```
SCATTER PLOT  (13) VTRN:CA*SYS1TDS:5   N= 70 OUT OF 70  14.UMPGMINU VS. 2.FTPNDX
```



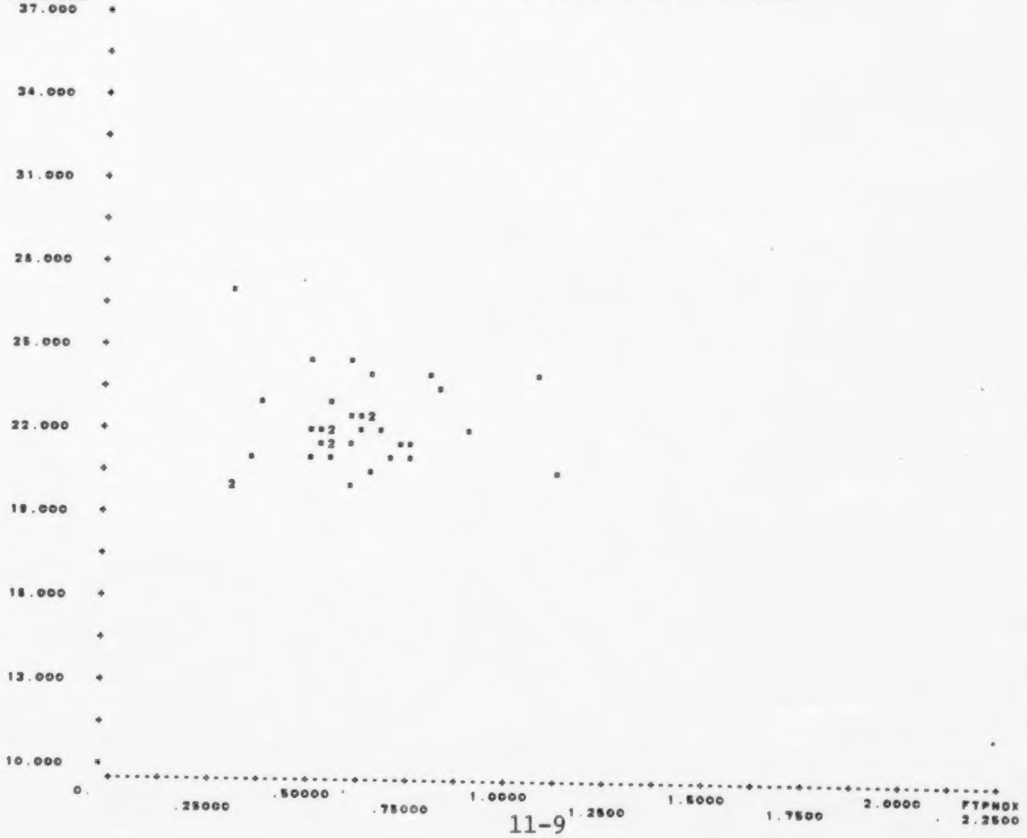
```
SCATTER PLOT  (14) VTRN:CM*SYS1TDS:5   N= 37 OUT OF 37  14.UMPGMINU VS. 2.FTPNDX
```



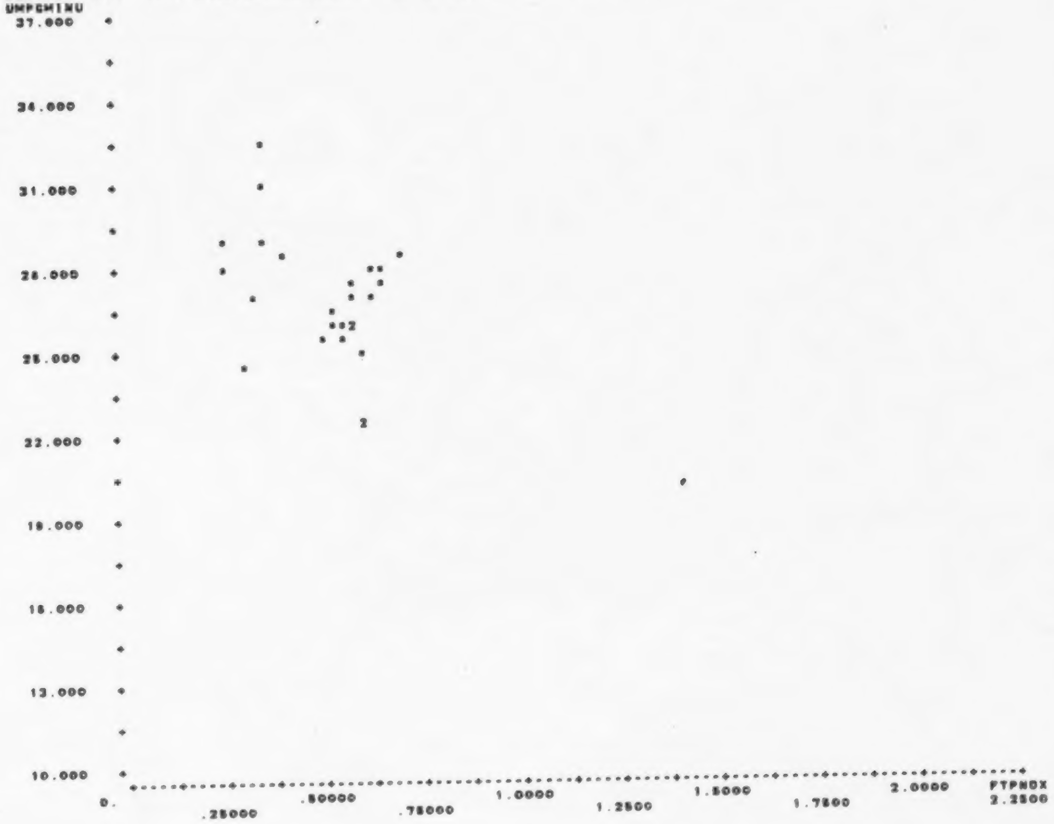
SCATTER PLOT (15) VTRN:LA*SYS1TD6:5 N= 22 OUT OF 22 14.UMPGMINU VS. 3.FTPNOX



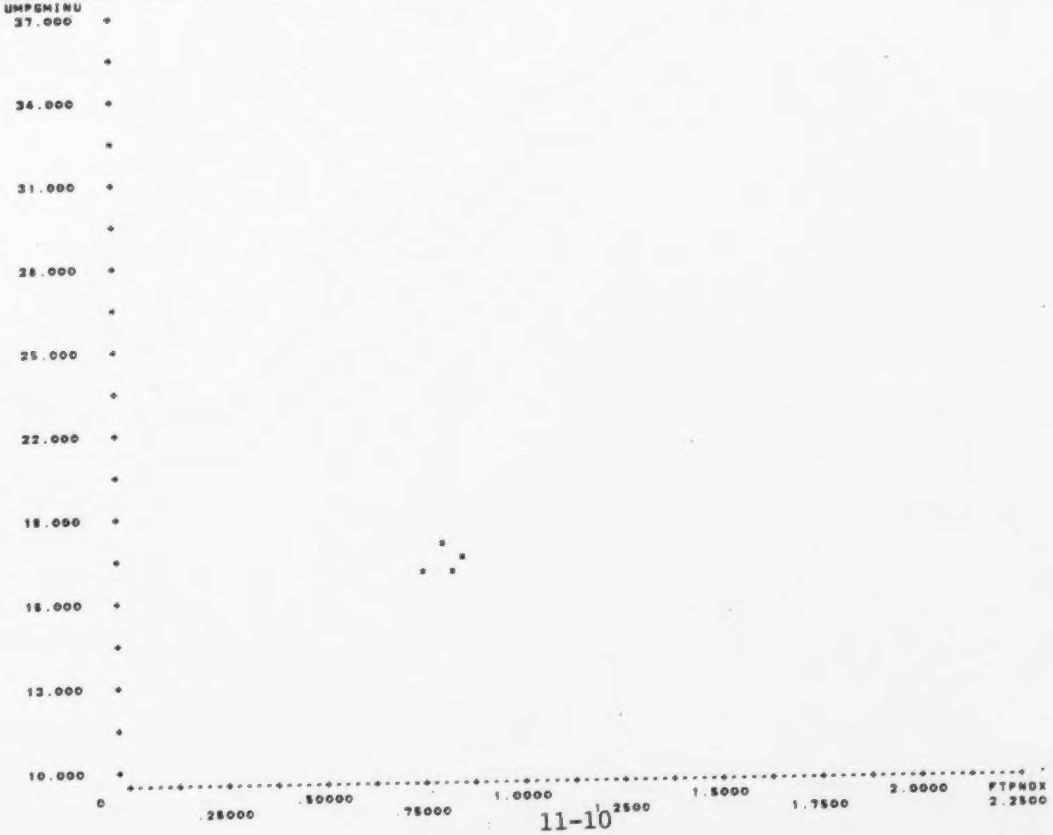
SCATTER PLOT (15) VTRN:CA*SYS1TD8:6 N= 38 OUT OF 38 14.UMPGMINU VS. 3.FTPNOX

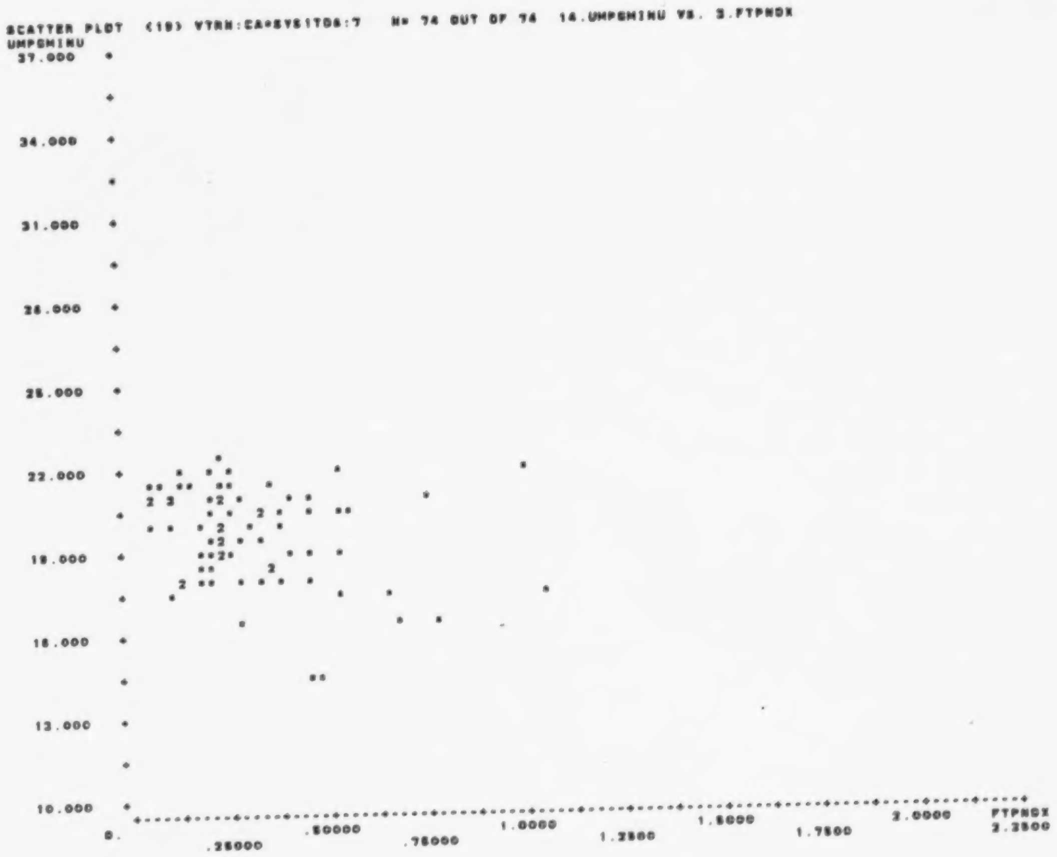


SCATTER PLOT (17) VTRN:CM*SYS1TD8:5 N= 25 OUT OF 25 14.UMPGMINU VS. 3.FTPNOX

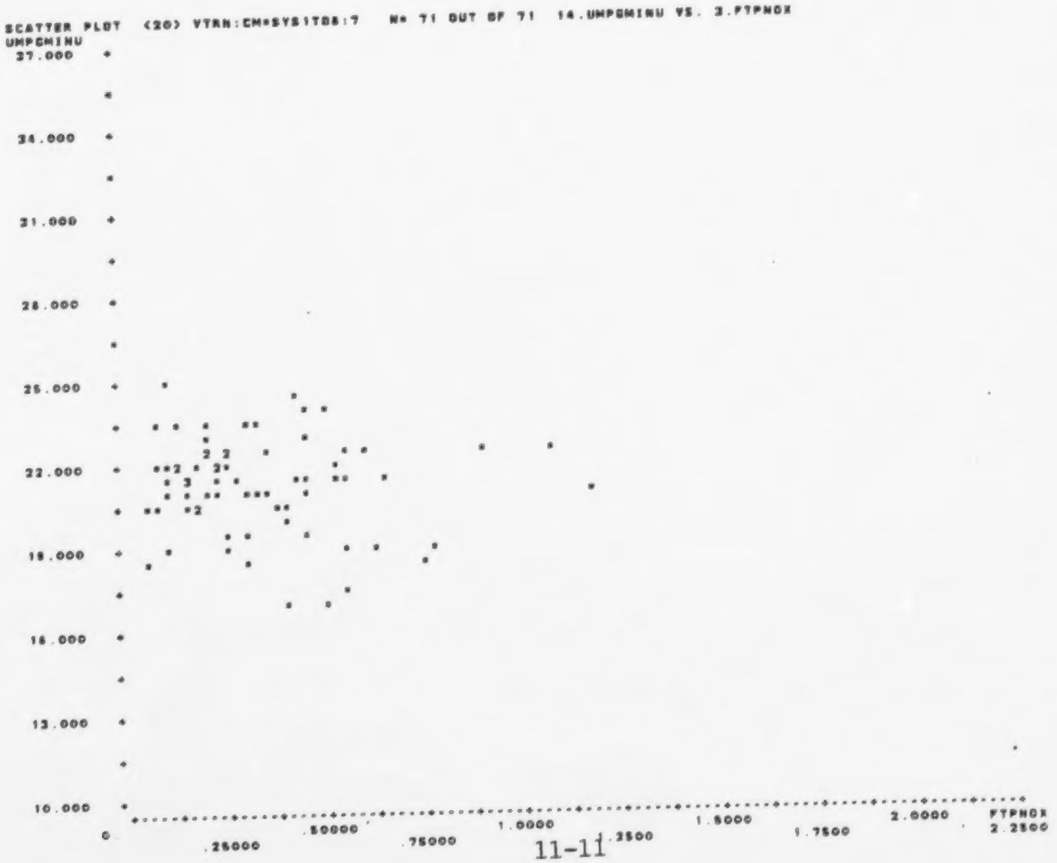


SCATTER PLOT (18) VTRN:LA*SYS1TD8:5 N= 4 OUT OF 4 14.UMPGMINU VS. 3.FTPNOX



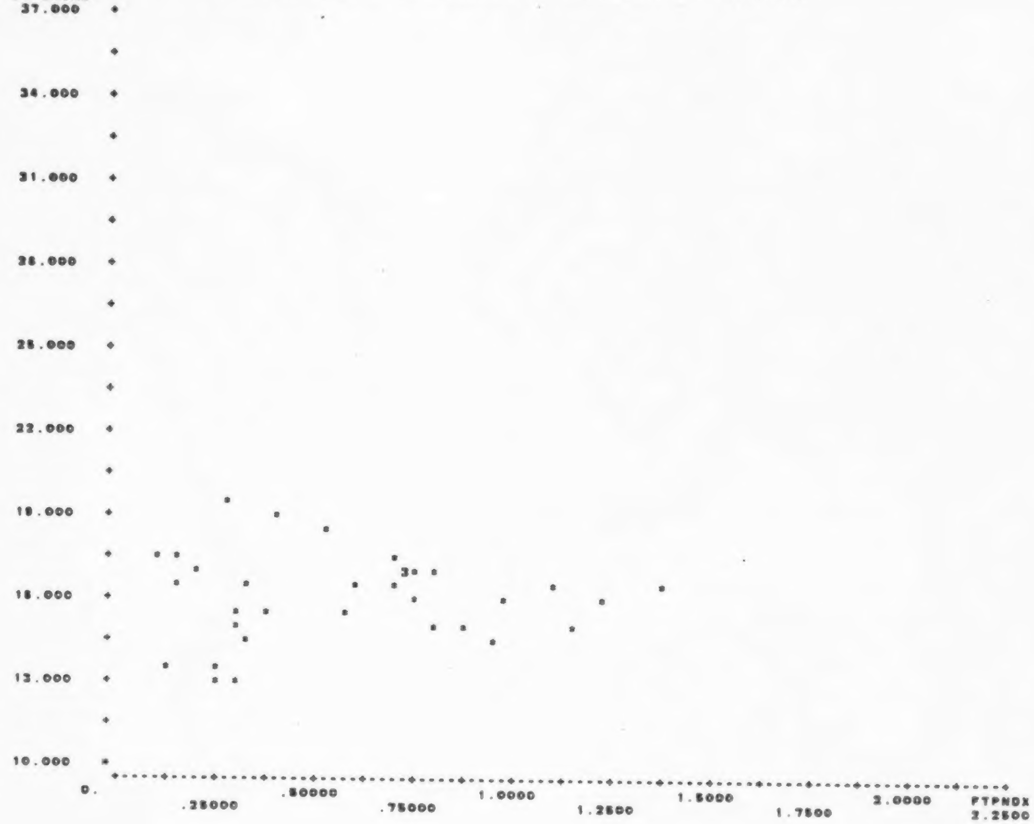


SCATTER PLOT (19) VTRN:CA*SYS1TD8:7 N= 74 OUT OF 74 14.UMPGMINU VS. 3.FTPNOX

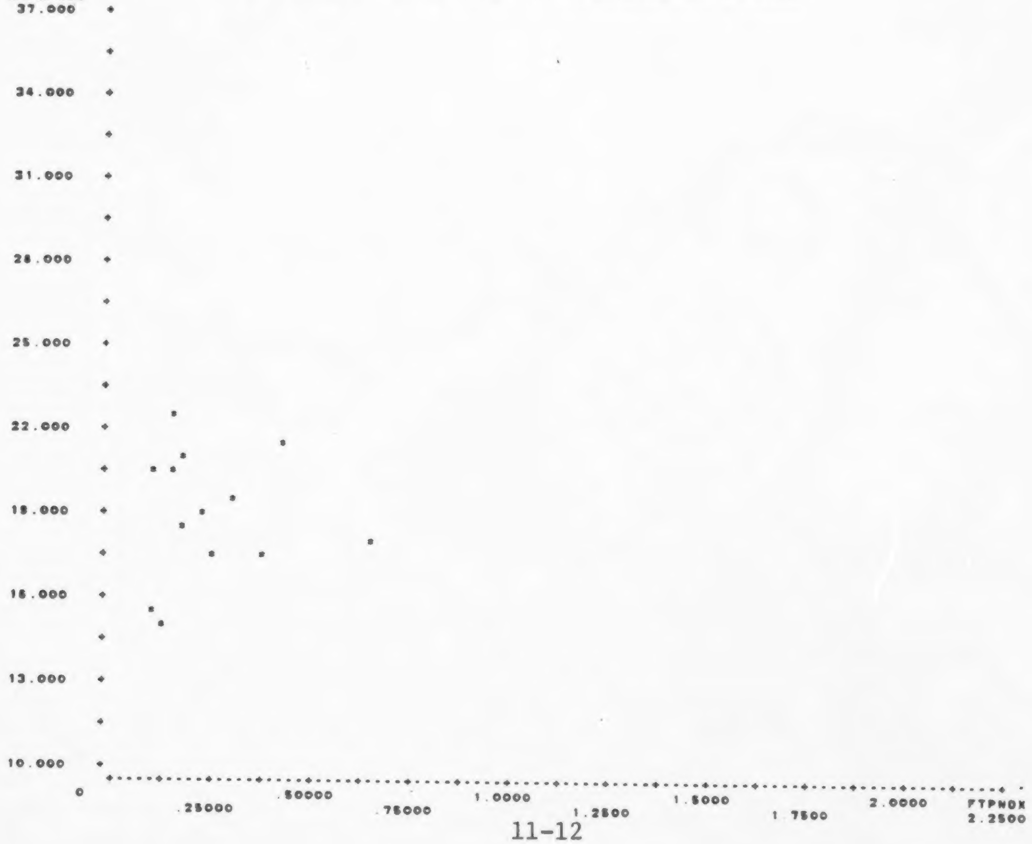


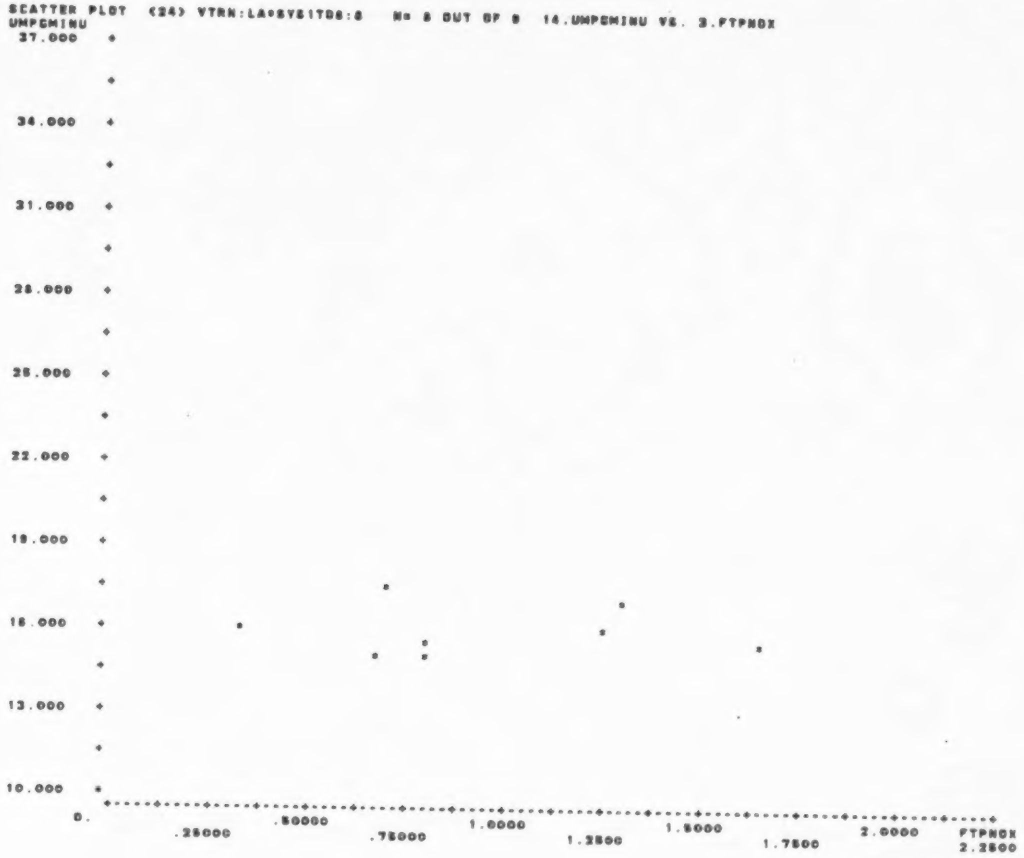
SCATTER PLOT (20) VTRN:CM*SYS1TD8:7 N= 71 OUT OF 71 14.UMPGMINU VS. 3.FTPNOX

SCATTER PLOT (22) VTRN:CA*SYS1T08:8 N= 34 OUT OF 34 14.UMPCMINU VS. 3.FTPNOX



SCATTER PLOT (23) VTRN:CM*SYS1T08:8 N= 13 OUT OF 13 14.UMPCMINU VS. 3.FTPNOX





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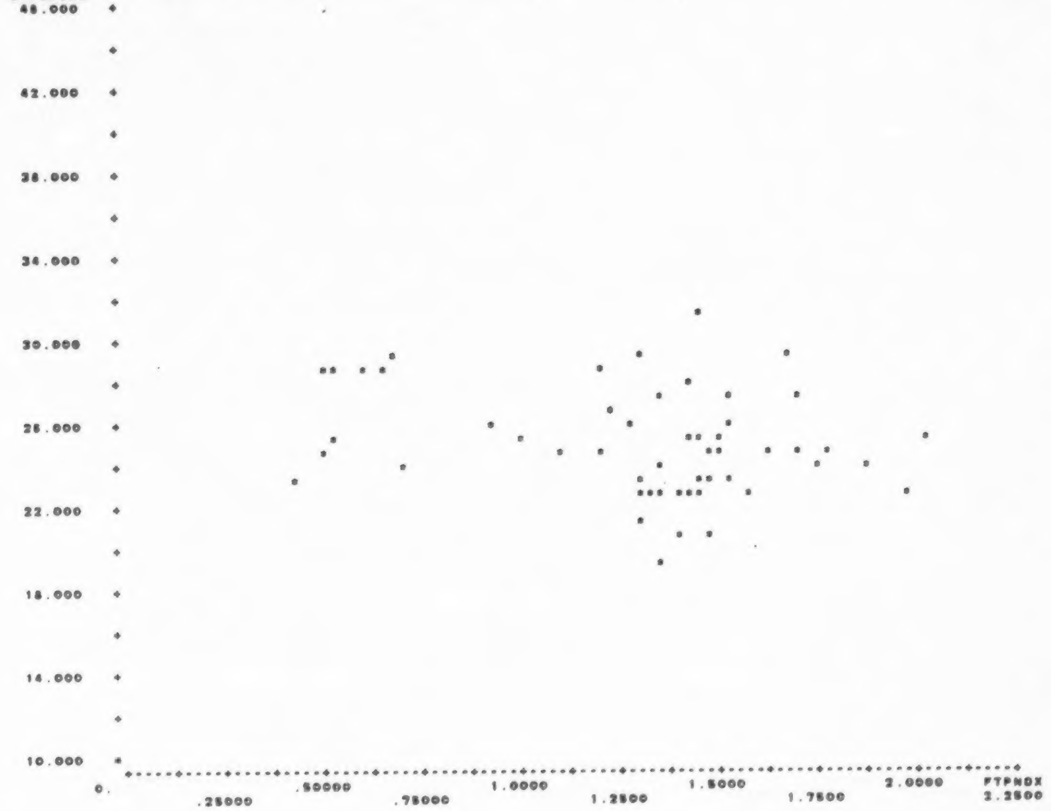
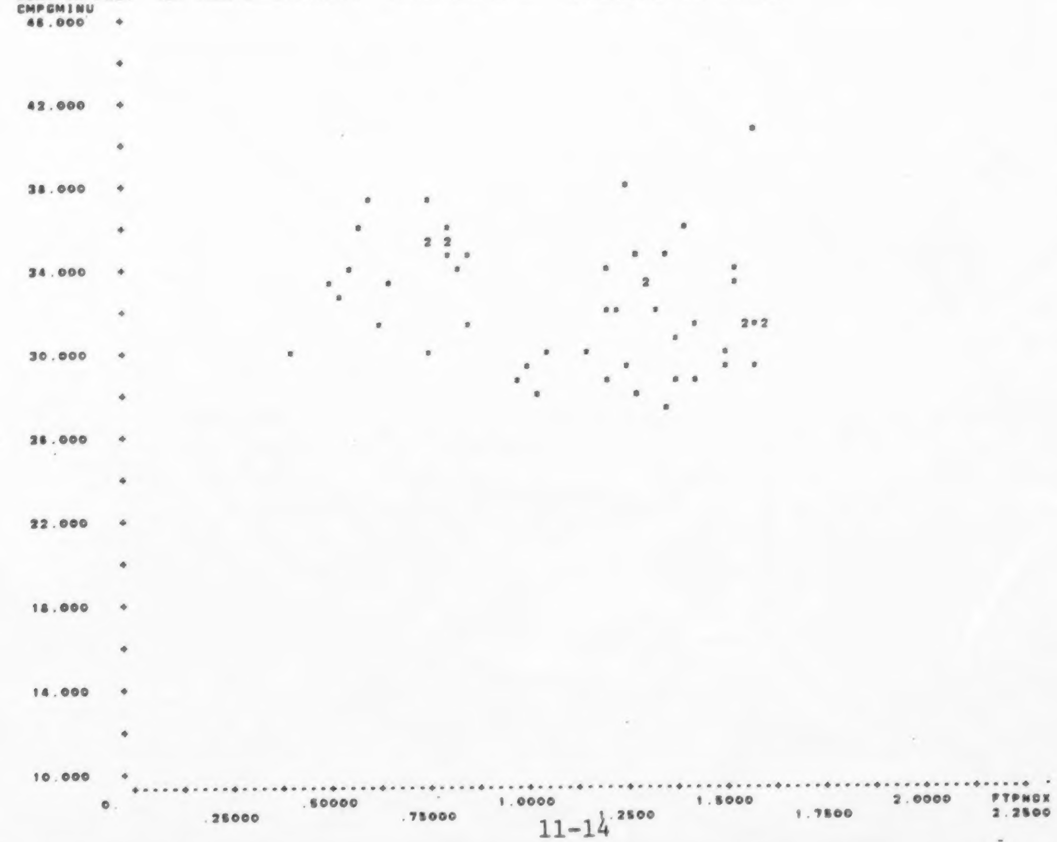
SCATTER PLOT  (24) VTRN:LA*SYS1TDS:8   N= 8 OUT OF 8  14.UMPGMINU VS. 3.FTPNOX
```

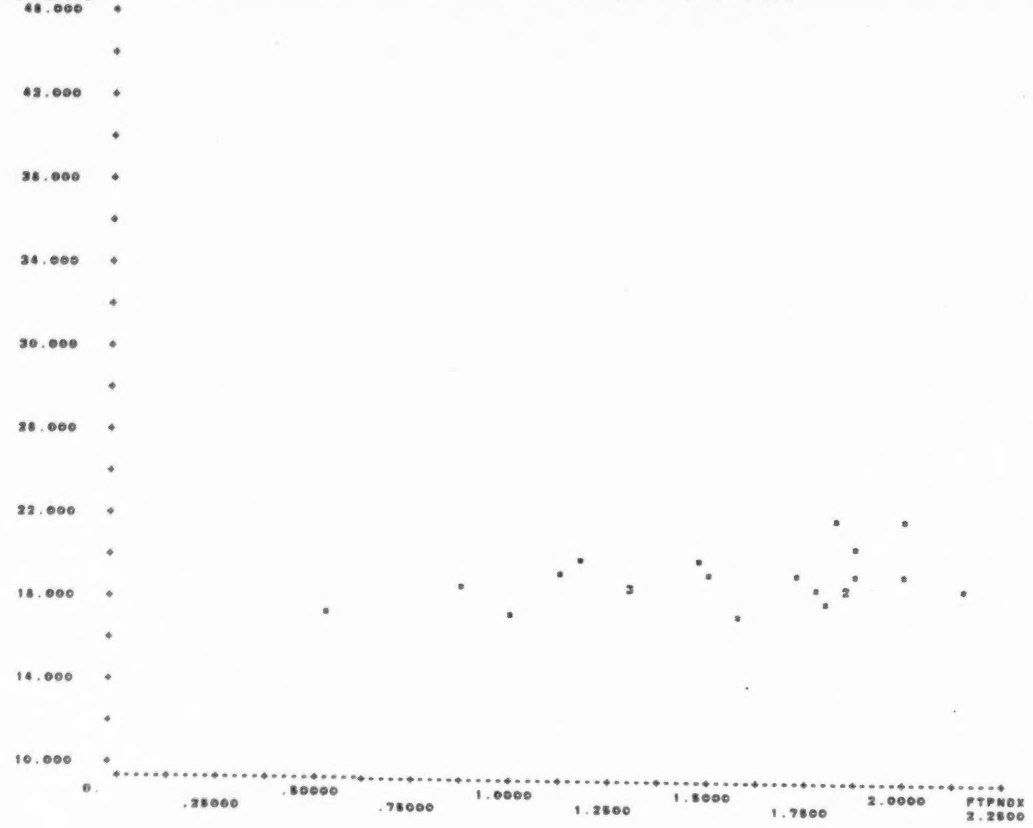
<SCATTER SYST VAR=16;3 STRAT=V26*V102 SCATTER PLOT (1) VTRN:CA*SYS1TOS:1 N= 52 OUT OF 78 16.CMPGMINU VS. 3.FTPNOX



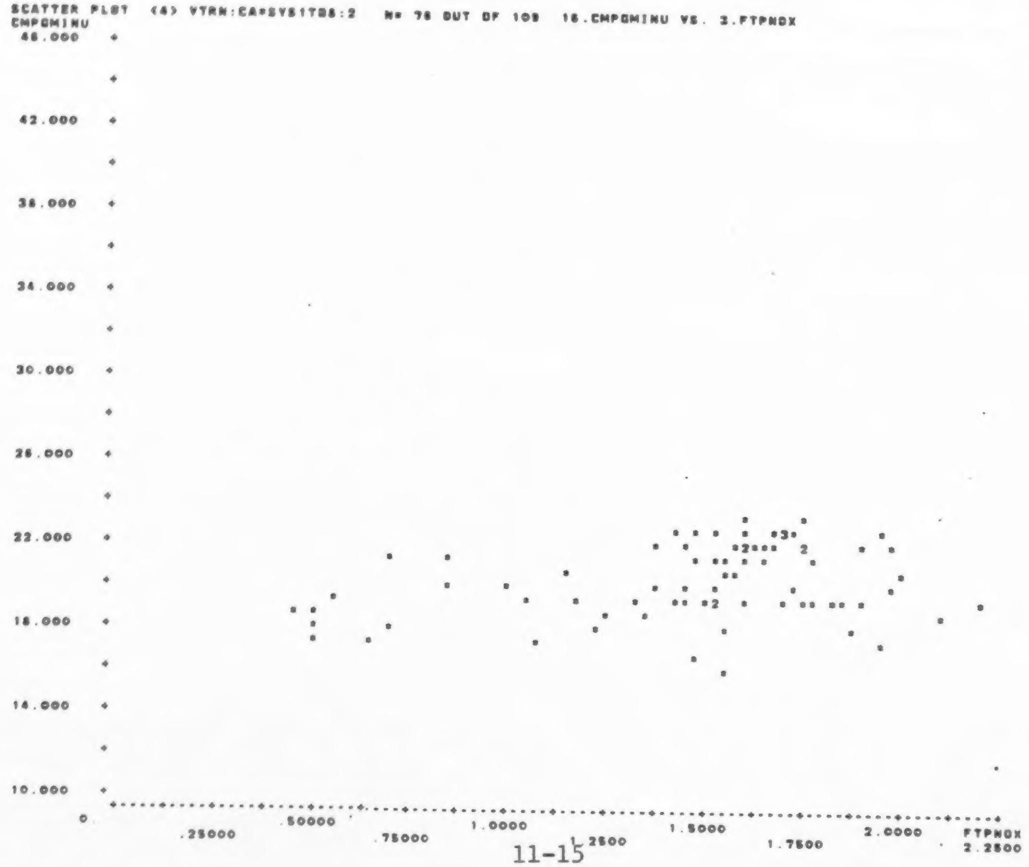
SCATTER PLOT (2) VTRN:CM*SYS1TOS:1 N= 53 OUT OF 84 16.CMPGMINU VS. 3.FTPNOX



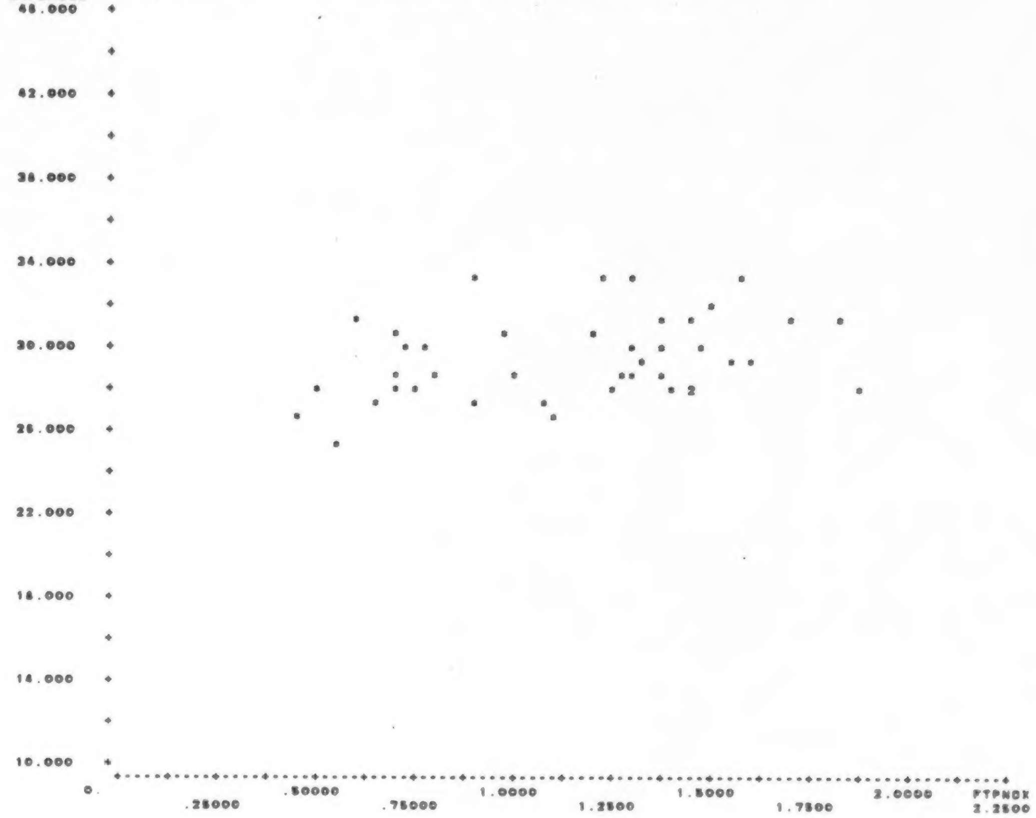
SCATTER PLOT (3) VTRN:LA*SYS1TDS:1 N= 22 OUT OF 27 18.CMPGMINU VS. 3.FTPNOX



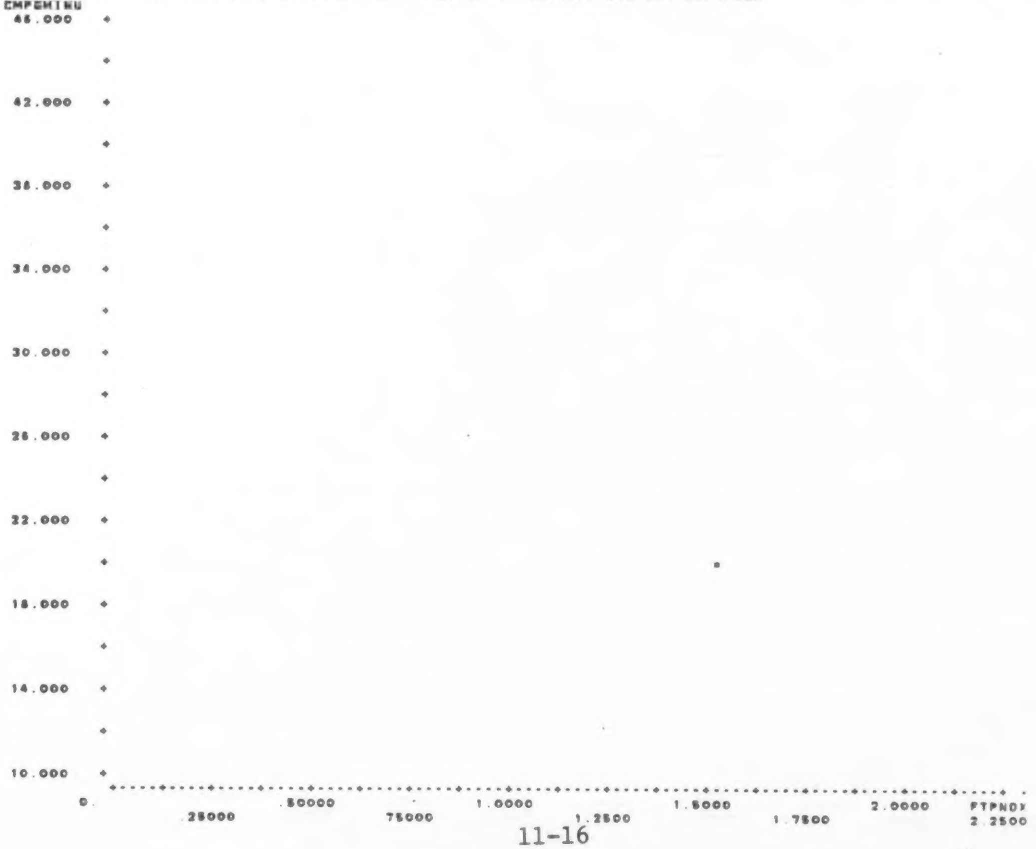
SCATTER PLOT (4) VTRN:CA*SYS1TDS:2 N= 76 OUT OF 109 18.CMPGMINU VS. 3.FTPNOX



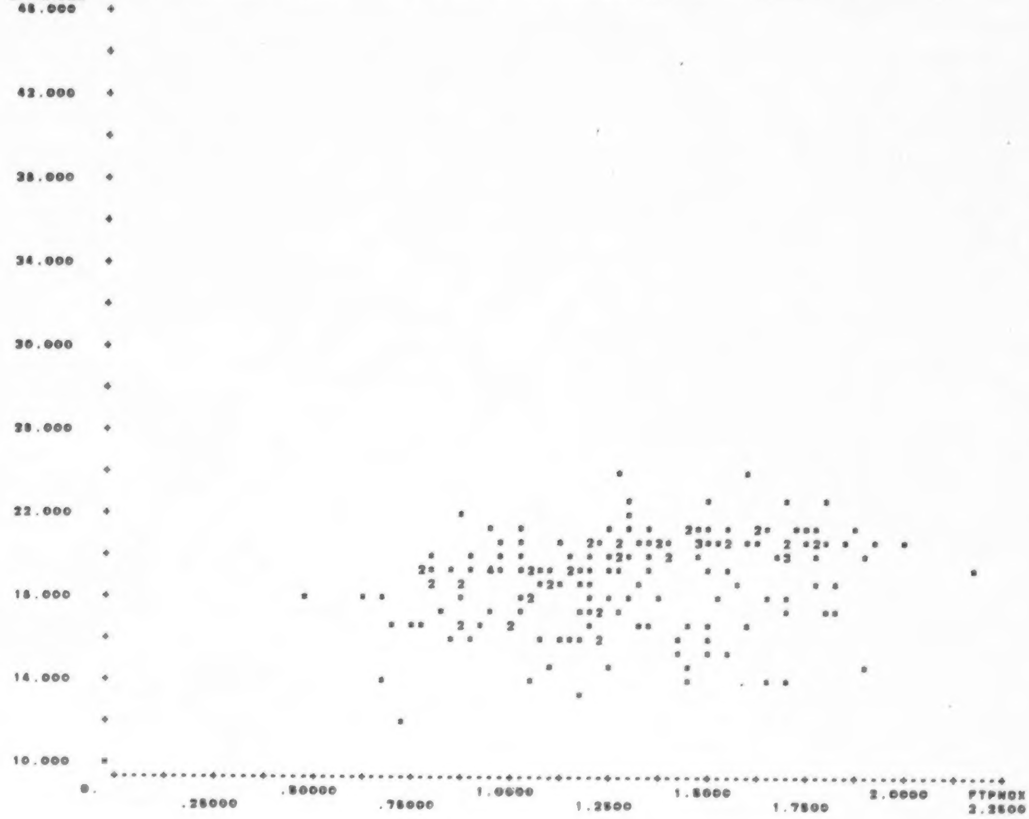
SCATTER PLOT (5) VTRN:CM*SYS1T08:2 N= 41 OUT OF 54 15.CMPGMINU VS. 3.FTPNOX



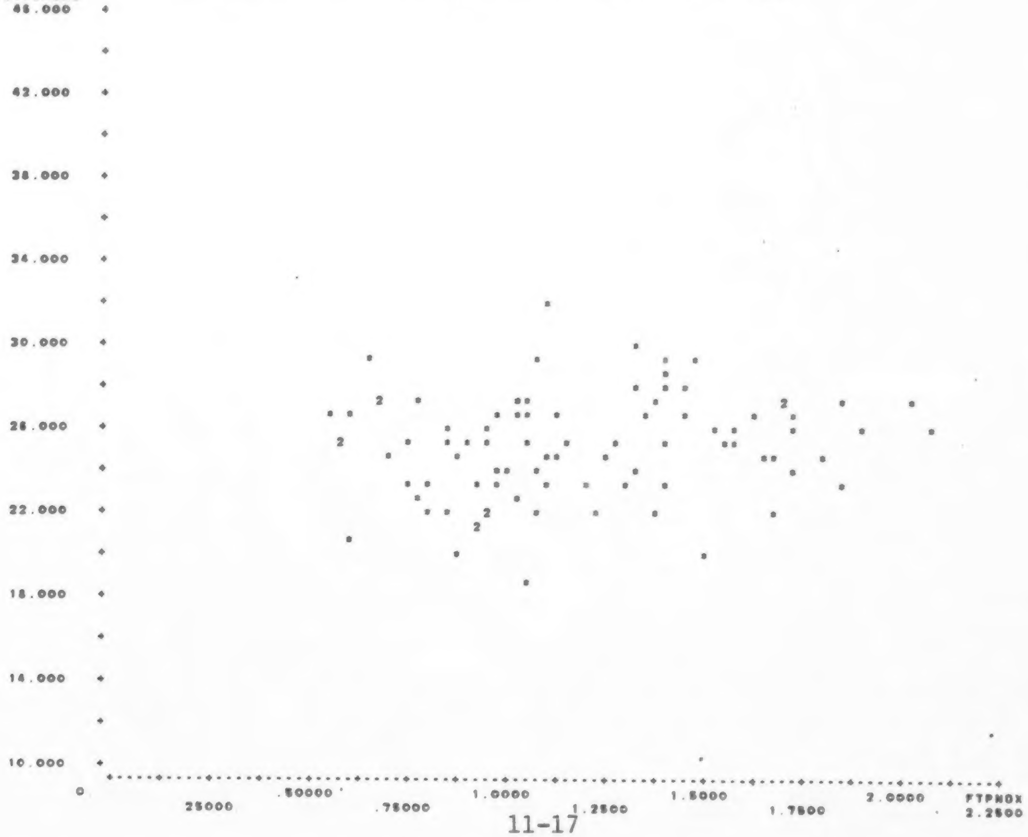
SCATTER PLOT (5) VTRN:LA*SYS1T08:2 N= 1 OUT OF 1 15.CMPGMINU VS. 3.FTPNOX



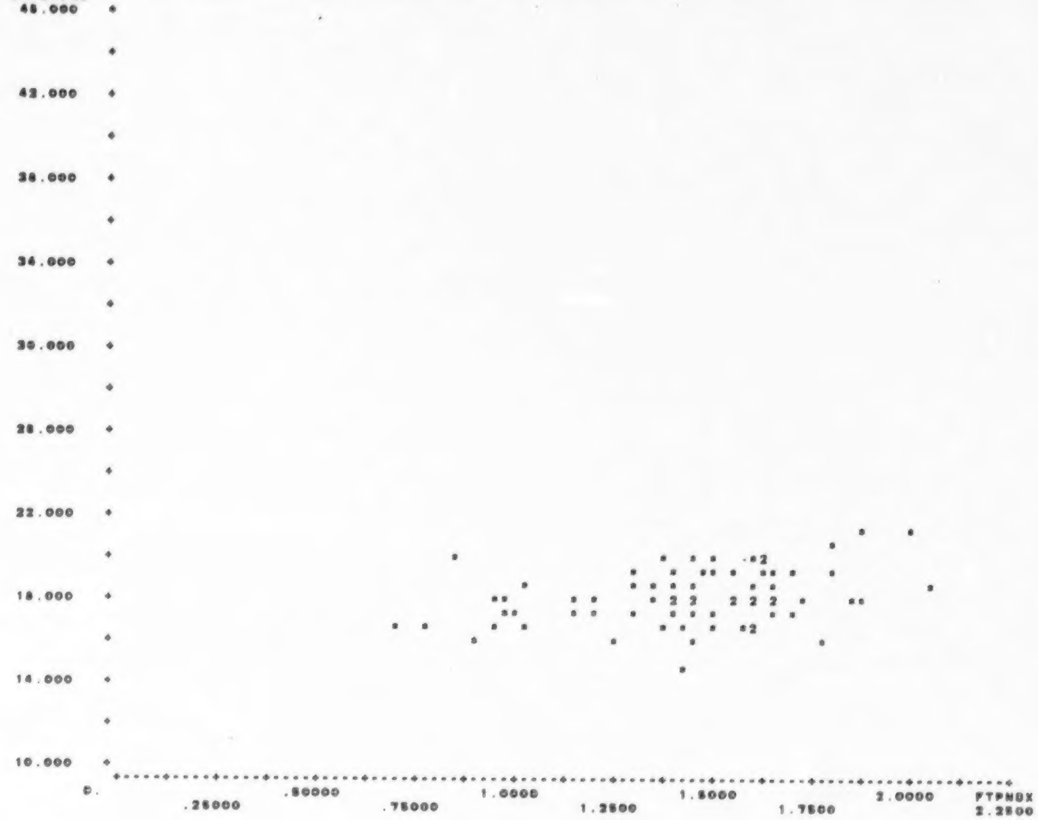
```
SCATTER PLOT  (7) VTRN:CA*SYS1TD8:3   N= 176 OUT OF 271  15.CMPGMINU VS. 3.FTPNOX
```



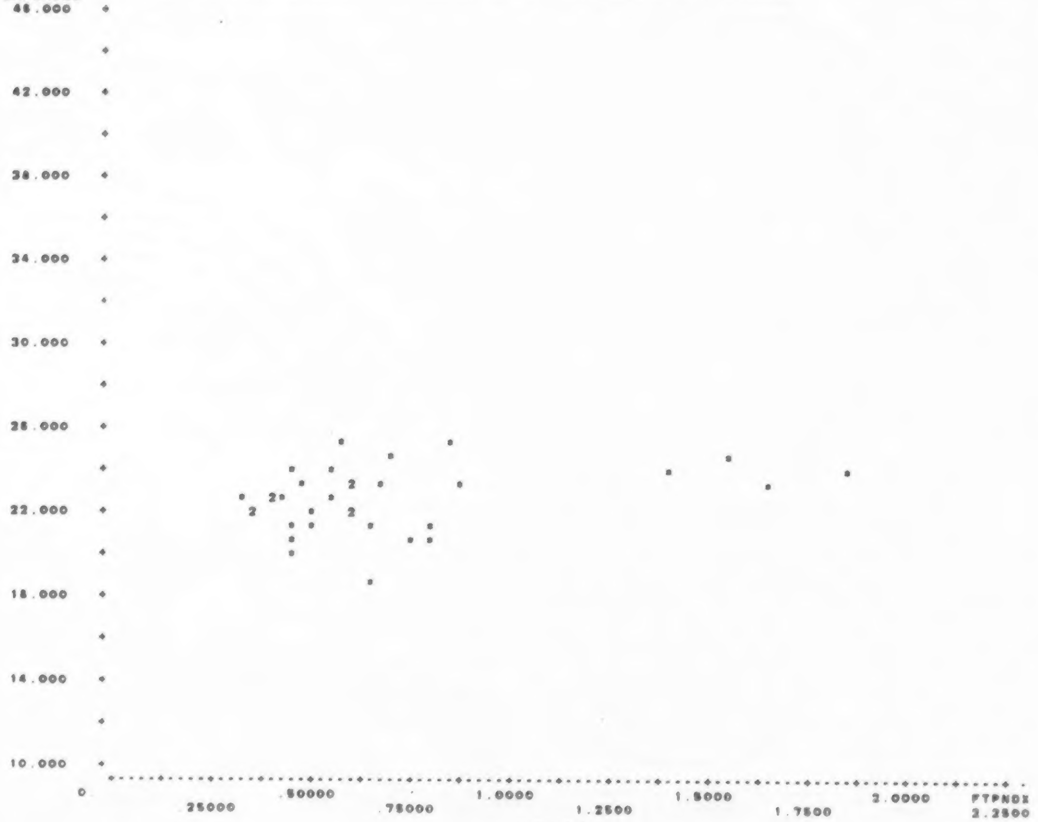
```
SCATTER PLOT  (8) VTRN:CM*SYS1TD8:3   N= 87 OUT OF 139  15.CMPGMINU VS. 3.FTPNOX
```

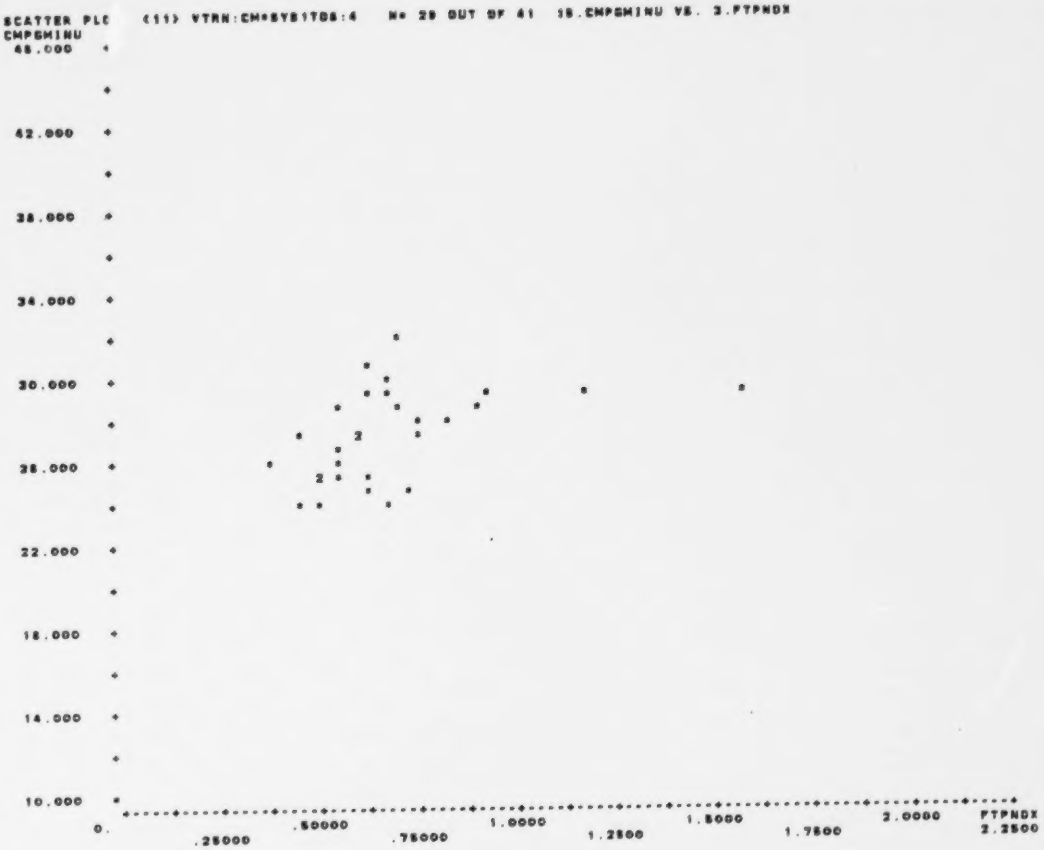


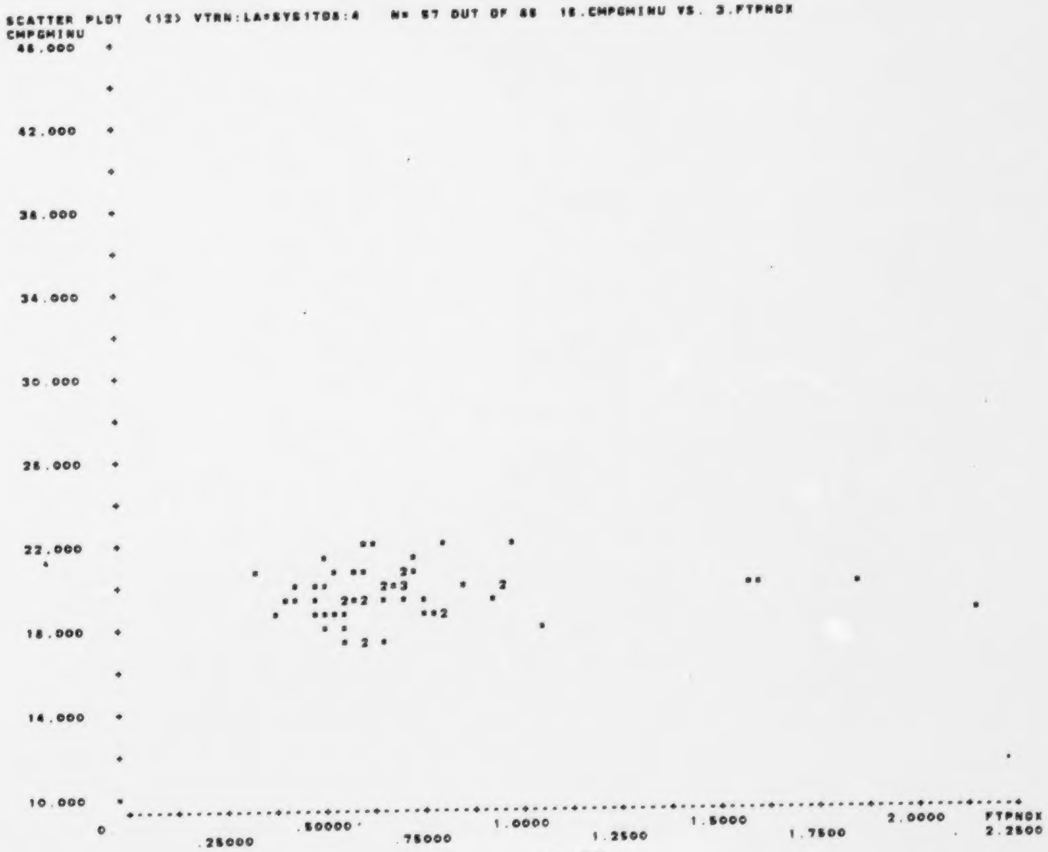
SCATTER PLOT (9) VTRN:LA=SYS1TOE:3 N= 70 OUT OF 81 15.CMPGMINU VS. 3.FTPNOX



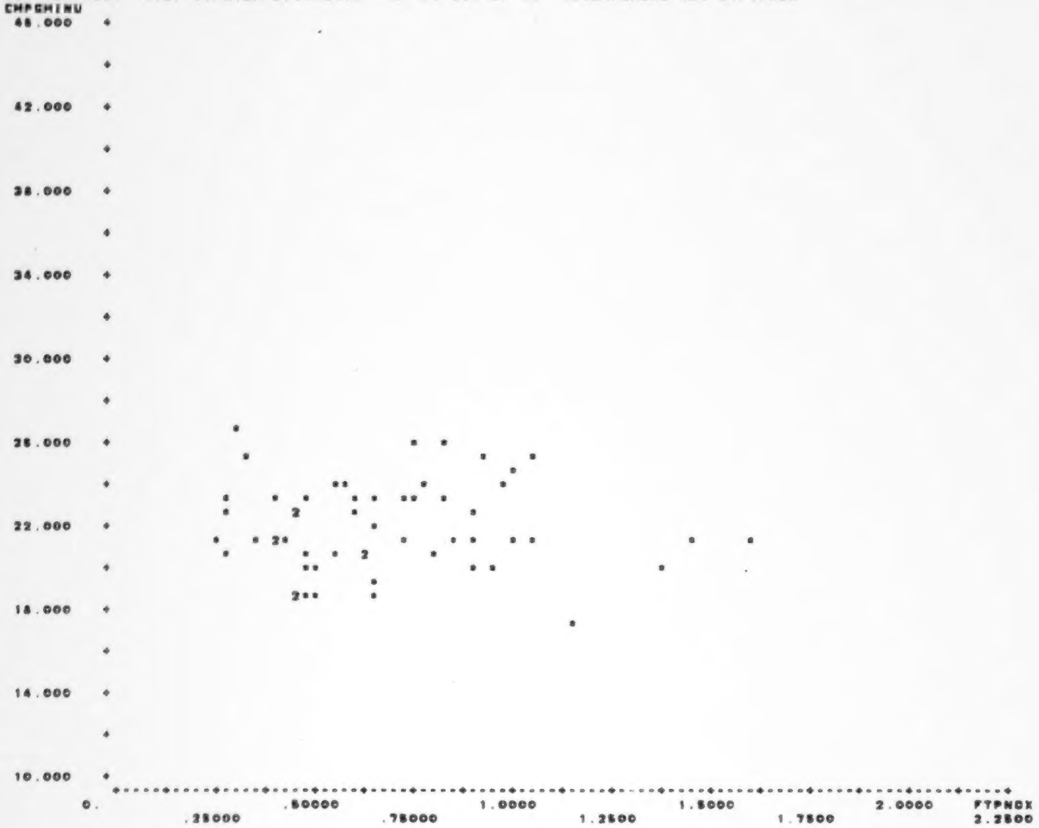
SCATTER PLOT (10) VTRN:CA=SYS1TOE:4 N= 33 OUT OF 45 15.CMPGMINU VS. 3.FTPNOX



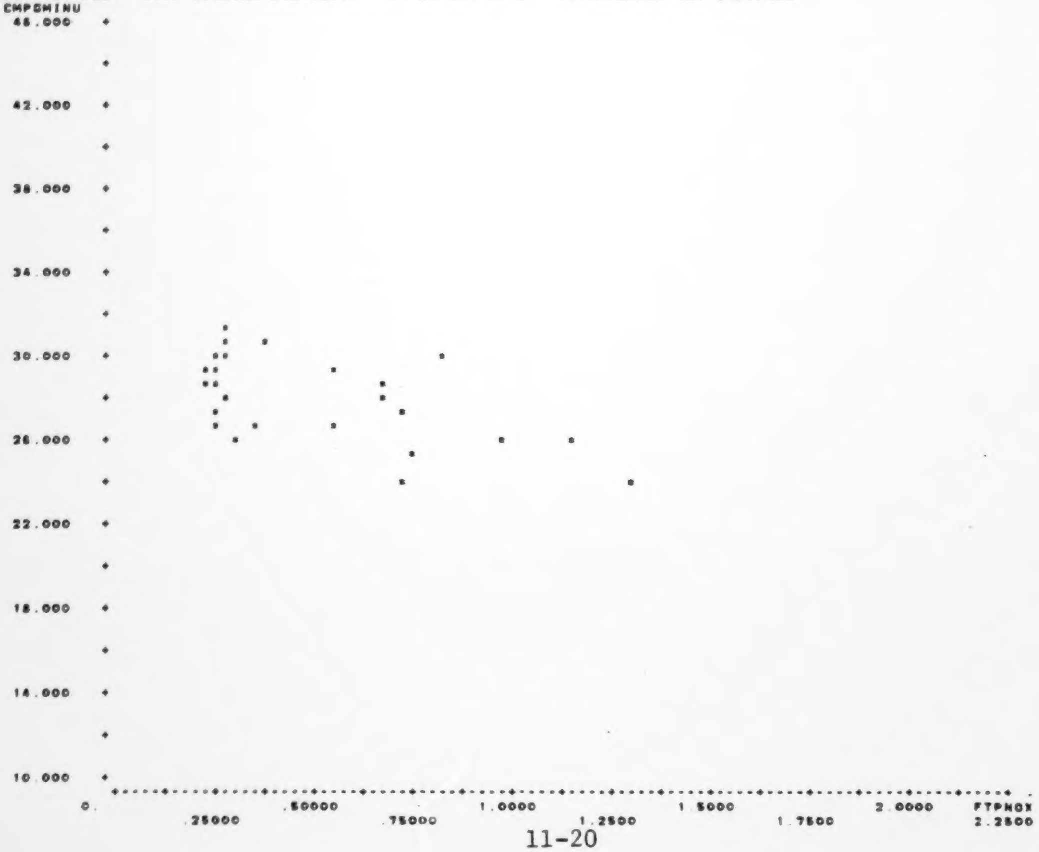

SCATTER PLC (11) VTRN:CM*SYS1TDS:4 N= 29 OUT OF 41 15.CMPGMINU VS. 3.FTPNOX
CMPGMINU
46.000
42.000
38.000
34.000
30.000
26.000
22.000
18.000
14.000
10.000
0.
.25000
.50000
.75000
1.0000
1.2500
1.5000
1.7500
2.0000
FTPNOX
2.2500


SCATTER PLOT (12) VTRN:LA*SYS1TDS:4 N= 57 OUT OF 65 15.CMPGMINU VS. 3.FTPNOX
CMPGMINU
46.000
42.000
38.000
34.000
30.000
26.000
22.000
18.000
14.000
10.000
0
.25000
.50000
.75000
1.0000
1.2500
1.5000
1.7500
2.0000
FTPNOX
2.2500

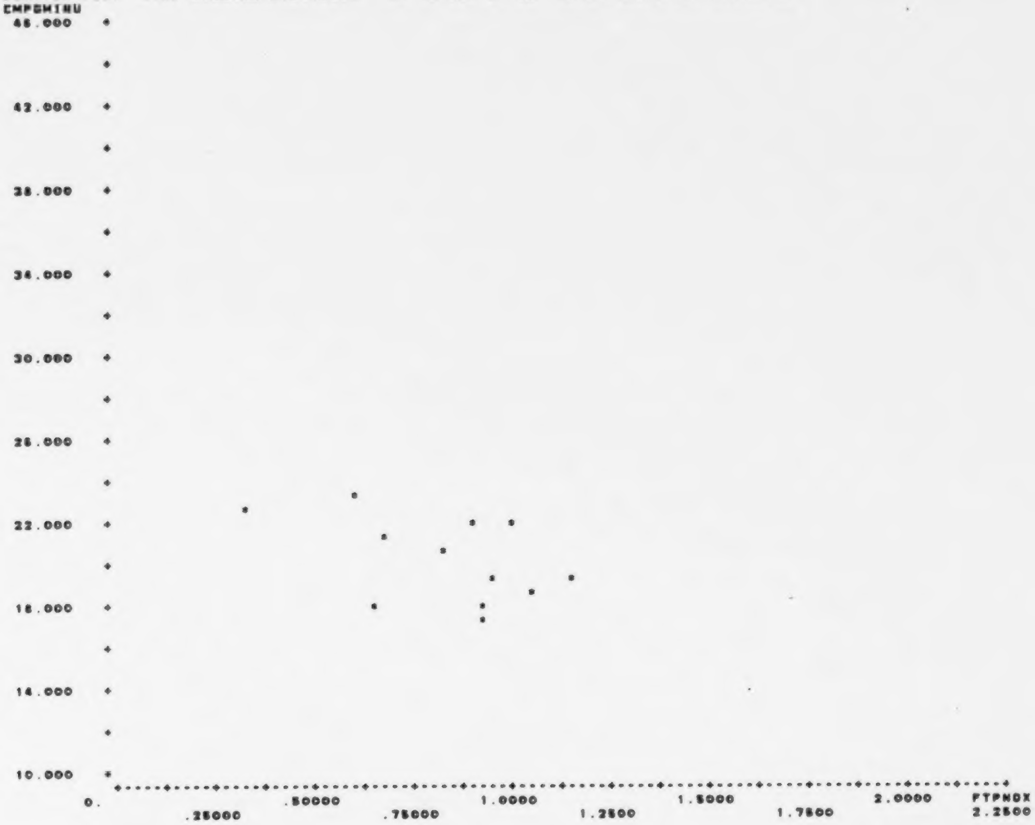
SCATTER PLOT (13) VTRN:CA=SYS1TD8:5 N= 55 OUT OF 70 18.CMPGMINU VS. 3.FTPNOX



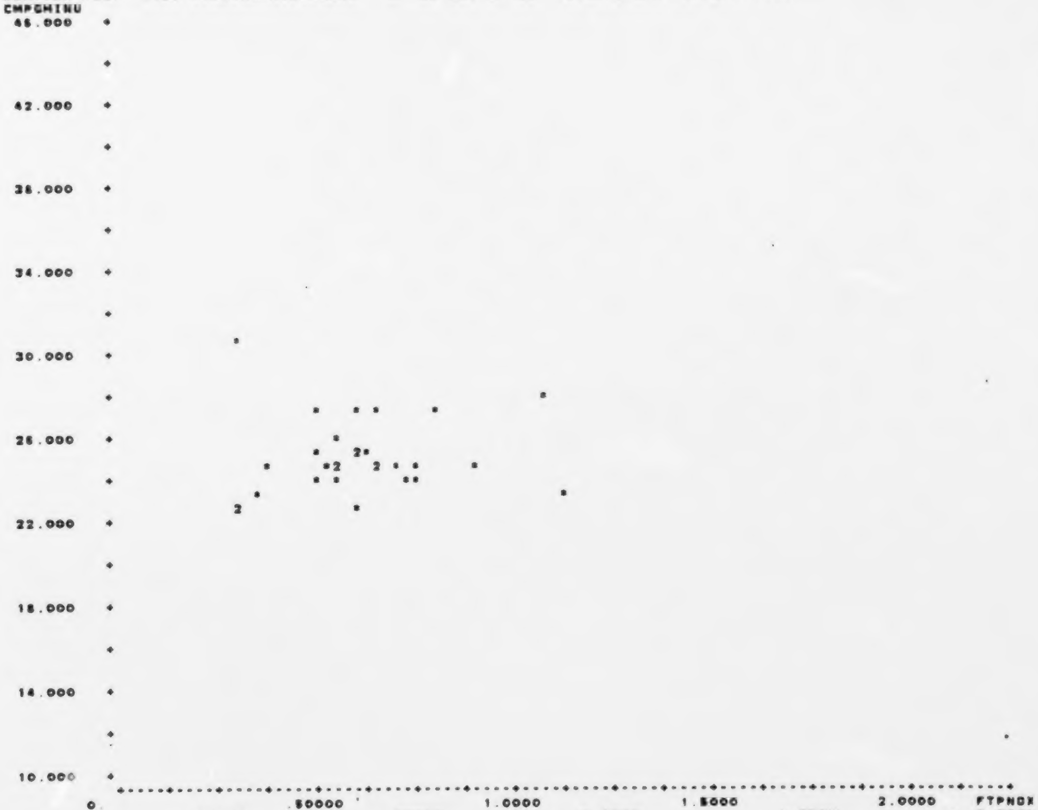
SCATTER PLOT (14) VTRN:CM=SYS1TD8:5 N= 25 OUT OF 37 18.CMPGMINU VS. 3.FTPNOX



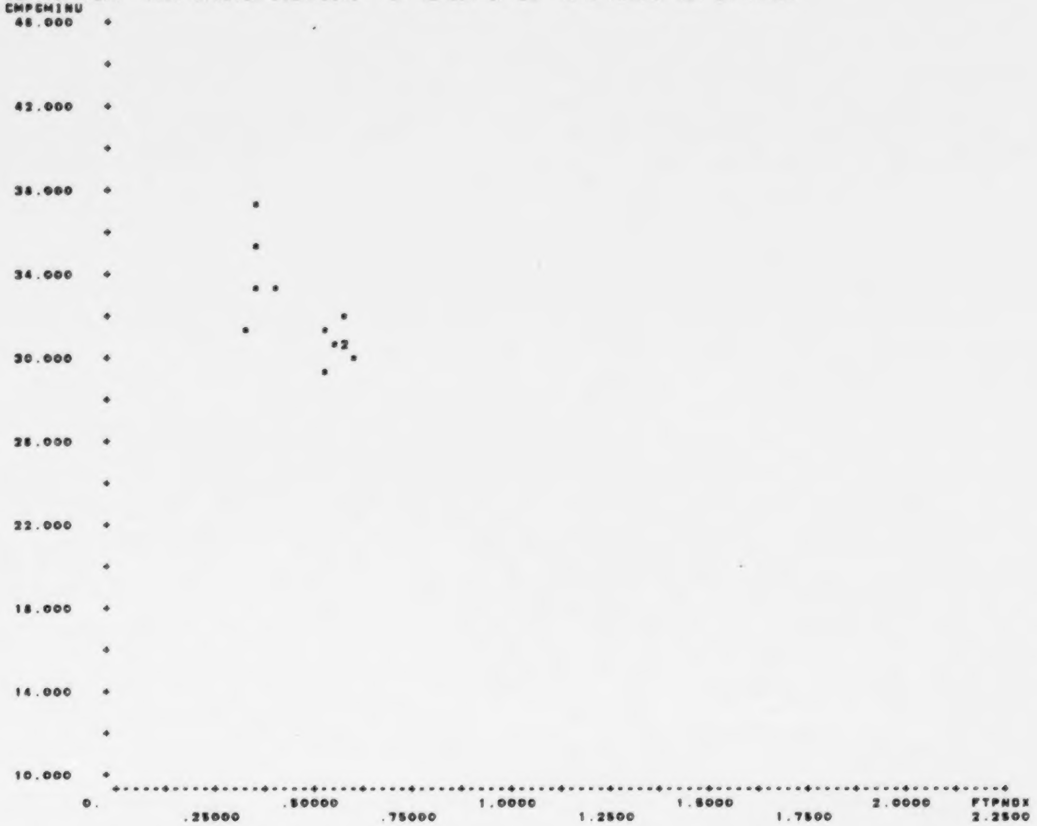
SCATTER PLOT (16) VTRN:LA*SYS1TD8:5 N= 12 OUT OF 22 16.CMPGMINU VS. 3.FTPNOX



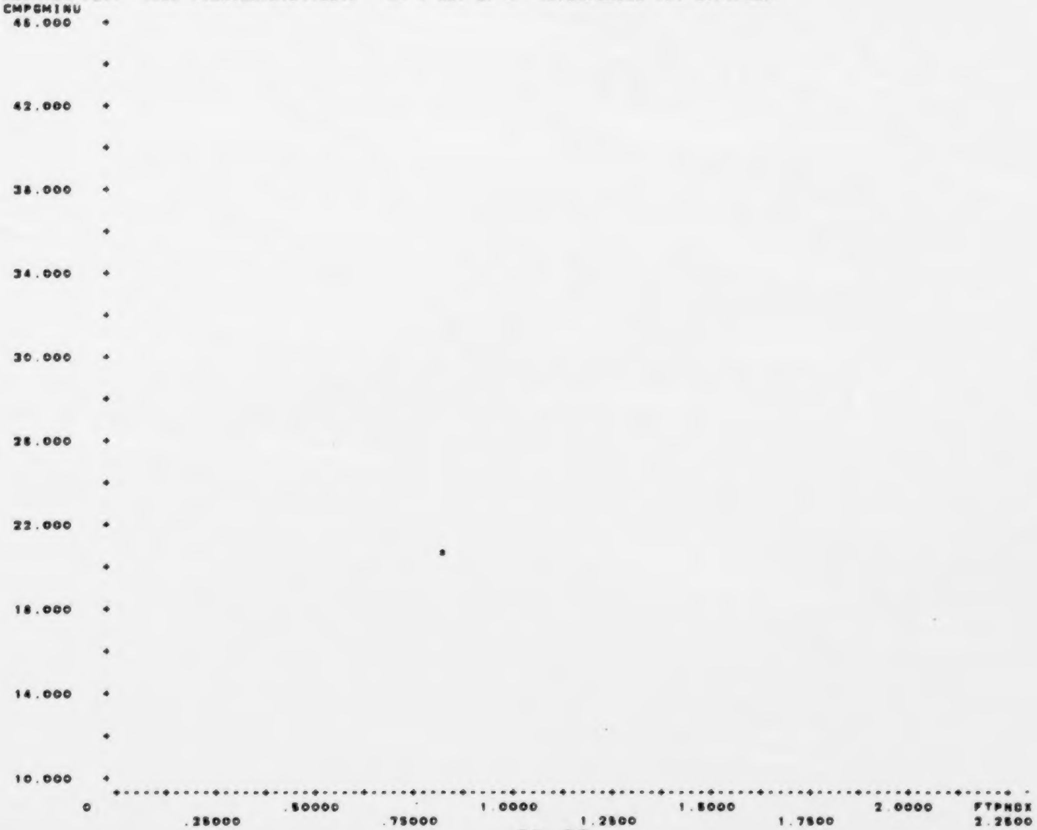
SCATTER PLOT (16) VTRN:CA*SYS1TD8:5 N= 28 OUT OF 36 16.CMPGMINU VS. 3.FTPNOX



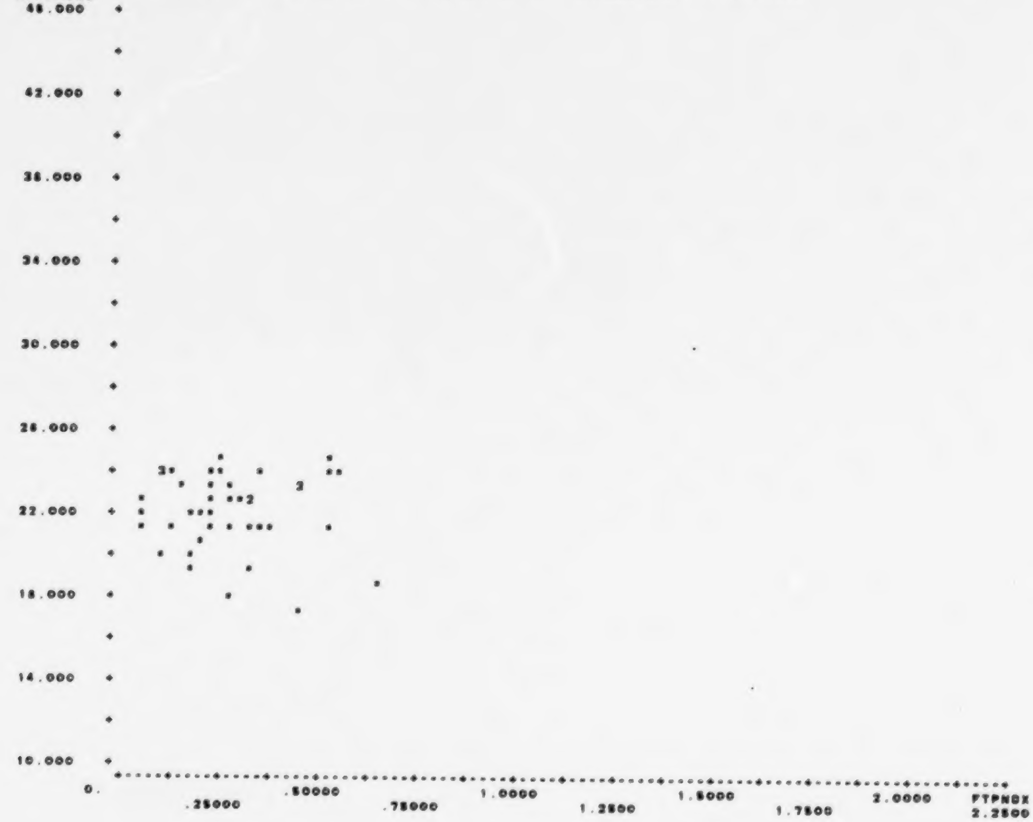
SCATTER PLOT (17) VTRN:CM*SYS1TD8:6 N= 12 OUT OF 25 16.CMPGMINU VS. 3.FTPNOX



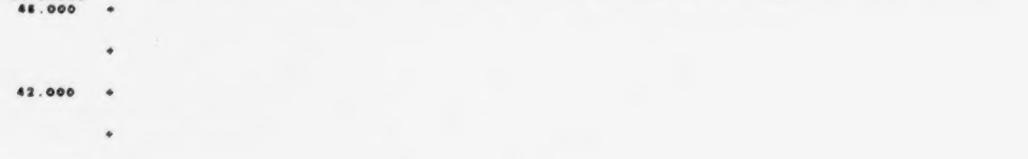
SCATTER PLOT (18) VTRN:LA*SYS1TD8:6 N= 1 OUT OF 4 16.CMPGMINU VS. 3.FTPNOX



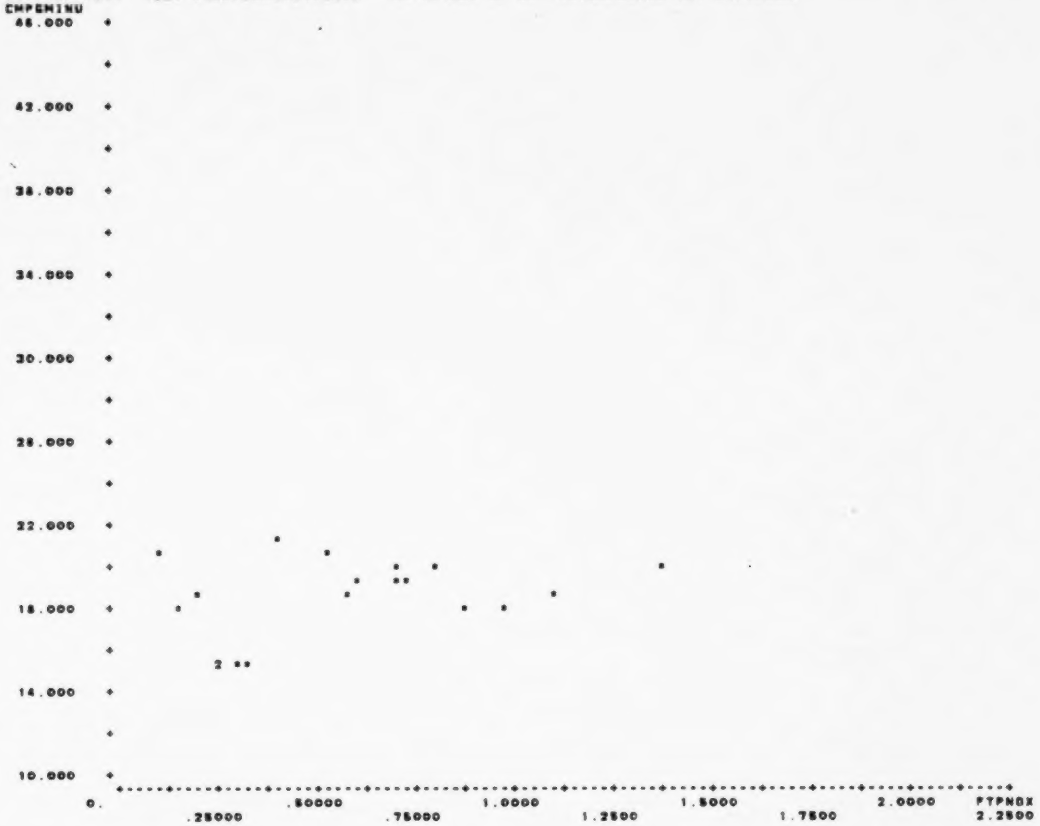
SCATTER PLOT (19) VTRN:CA*SYS1T08:7 N= 42 OUT OF 74 16.CMPGMINU VS. 3.FTPNOX



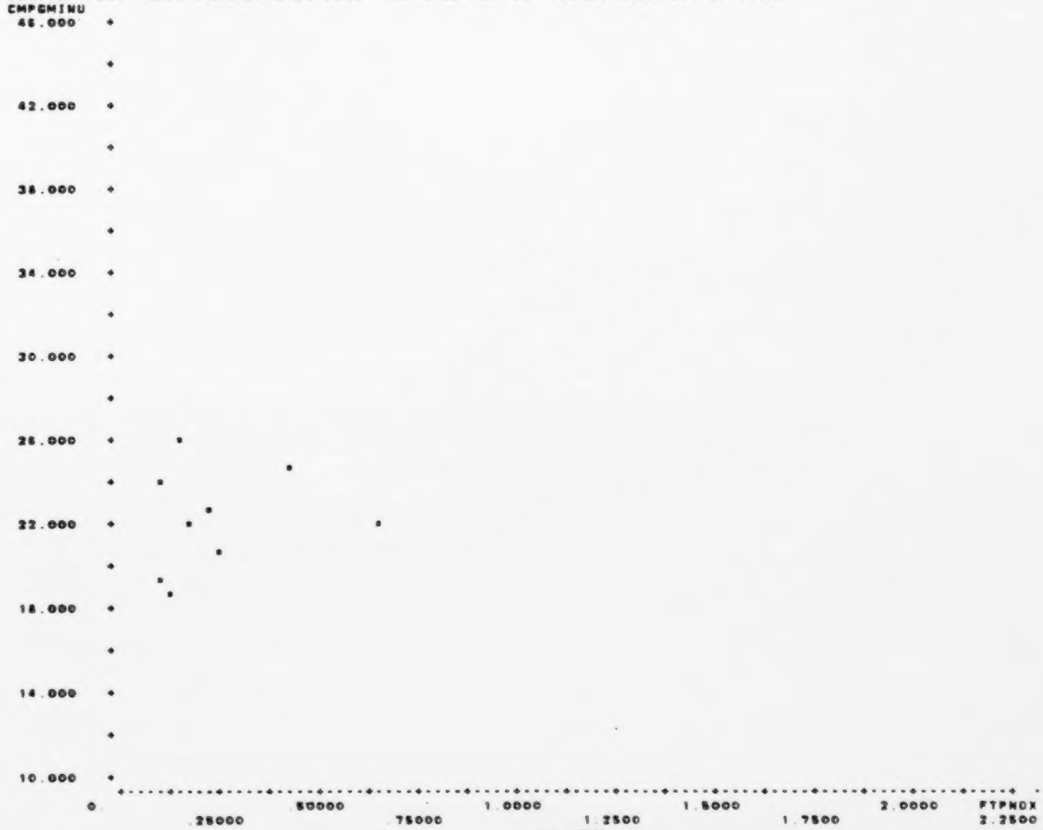
SCATTER PLOT (20) VTRN:CM*SYS1T08:7 N= 40 OUT OF 71 16.CMPGMINU VS. 3.FTPNOX



SCATTER PLOT (22) VTRN:CA*SYS1T08:8 N= 19 OUT OF 24 15.CMPGMINU VS. 3.FTPNOX



SCATTER PLOT (23) VTRN:CM*SYS1T08:8 N= 9 OUT OF 13 15.CMPGMINU VS. 3.FTPNOX



SCATTER PLOT (24) YTRN:LA=SYS1T08:8 N= 5 OUT OF 8 15.CMPGMINU VS. 3.FTPNOX